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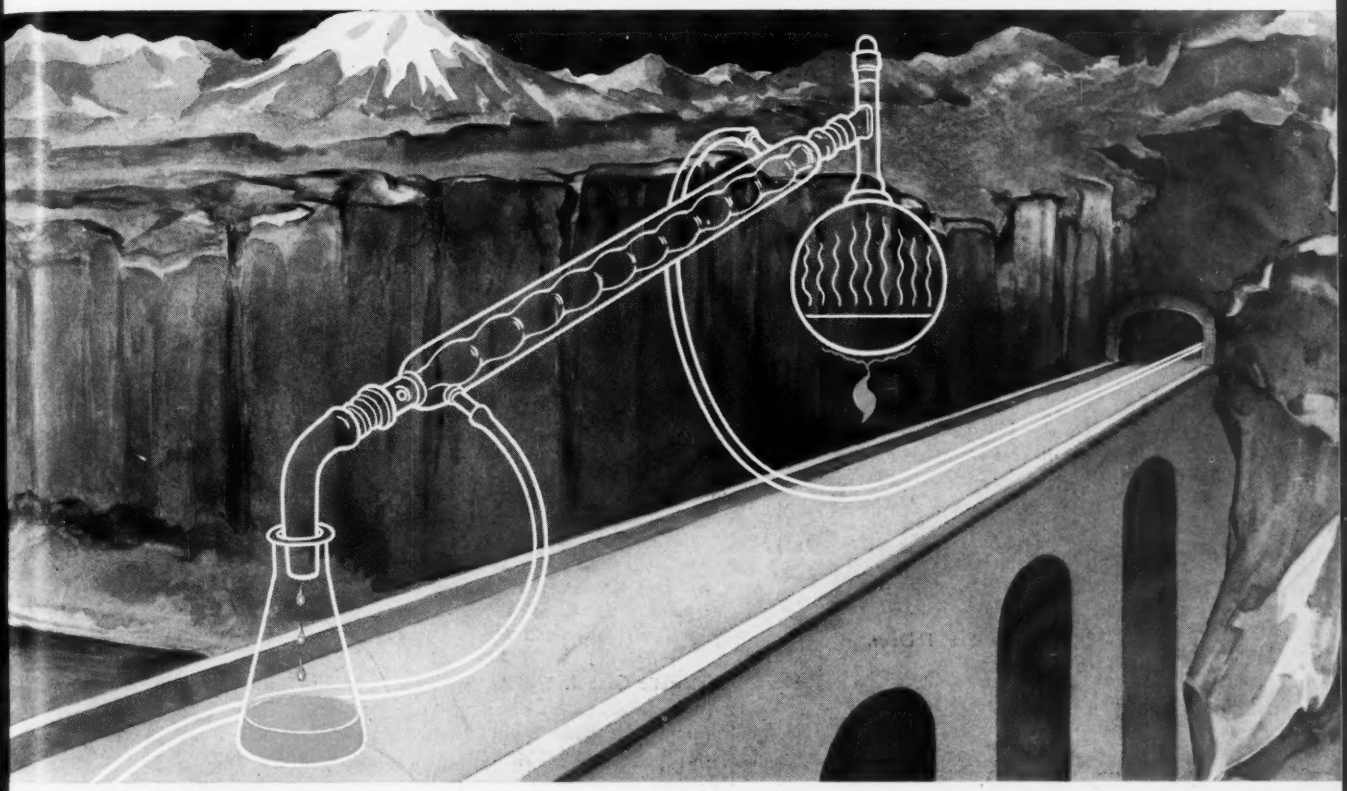
JUNE
1942

CHEMICAL EDUCATION



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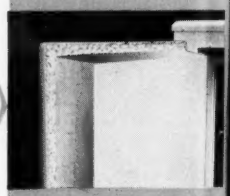

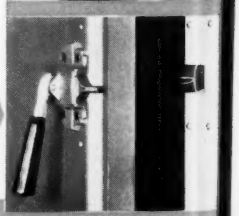

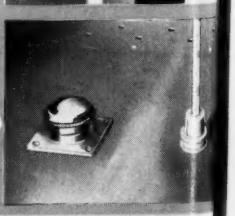

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VOL. 19 JUNE, 1942 NO. 6

Frontispiece—Geheimer Regierungs-Rat Professor Dr. Bernhard Tollens XV

Editor's Outlook 251

What's Been Going On 252

Division of Chemical Education—Minutes 252

Bernhard Tollens (1841–1918) and Some American Students of His School of Agricultural Chemistry, *C. A. Browne* 253

Meeting of the Society for the Promotion of Engineering Education 259

Round Table on the Problem of Teaching Chemistry

The Problem of Chemistry in General Education, *Theodore Askounes Ashford* .. 260

The Sequence of Topics in General Chemistry, *Joseph A. Babor* 263

The Varied Objectives in Service Courses in General Chemistry, *B. Clifford Hendricks* 265

The Importance of Laboratory Work in General Chemistry at the College Level, *C. S. Adams* 266

The Perennial Problem of Course Content in a Growing Science, *John E. Cavelti* 271

A Diagnostic and Remedial Study of Failures in Freshman Chemistry, *F. D. Martin* 274

Freshman Definitions 277

Formula of the Month 277

The Melting Point of Impure Organic Compounds, *Eugene Allen* 278

Summer Change of Address 281

Color Nomenclature in Qualitative Analysis, I. The Inter-Society Color Council Nomenclature, *L. P. Biefeld and Margaret Griffing* 282

On a Suggested Revision of the Seventh Period of the Periodic Table, *G. E. Villar* 286

High-School Chemistry

Glass, *F. C. Flint* 287

Letters 296

Out of the Editor's Basket 298

Recent Books 299

Trade Announcements XVIII

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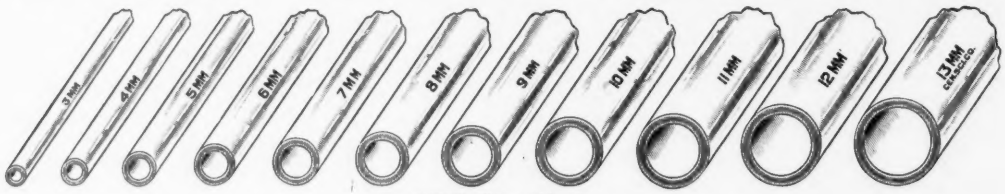

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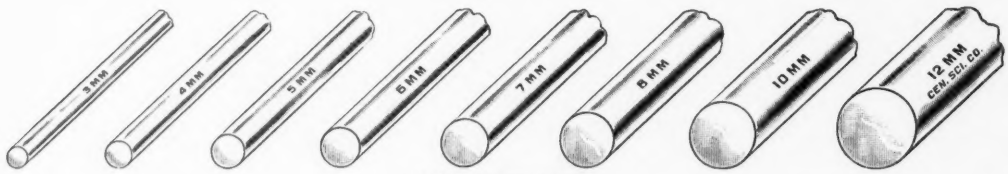
4	.75	585	18.00	20	1.40	56	7.20
5	1.05	338	12.00	22	1.40	49	7.20
6	1.05	270	12.00	25	1.45	41	7.20
7	1.10	218	10.20	28	1.15	45	9.60
8	1.10	188	10.20	30	1.25	37	9.60
9	1.15	158	9.00	32	1.35	34	9.60
10	1.15	139	9.00	35	1.35	30	9.60
11	1.20	120	9.00	38	1.40	26	11.40
12	1.20	109	9.00	41	1.40	26	11.40
13	1.20	101	9.00	45	1.50	23	13.20
14	1.30	86	7.20	51	1.60	19	13.20
16	1.30	75	7.20				



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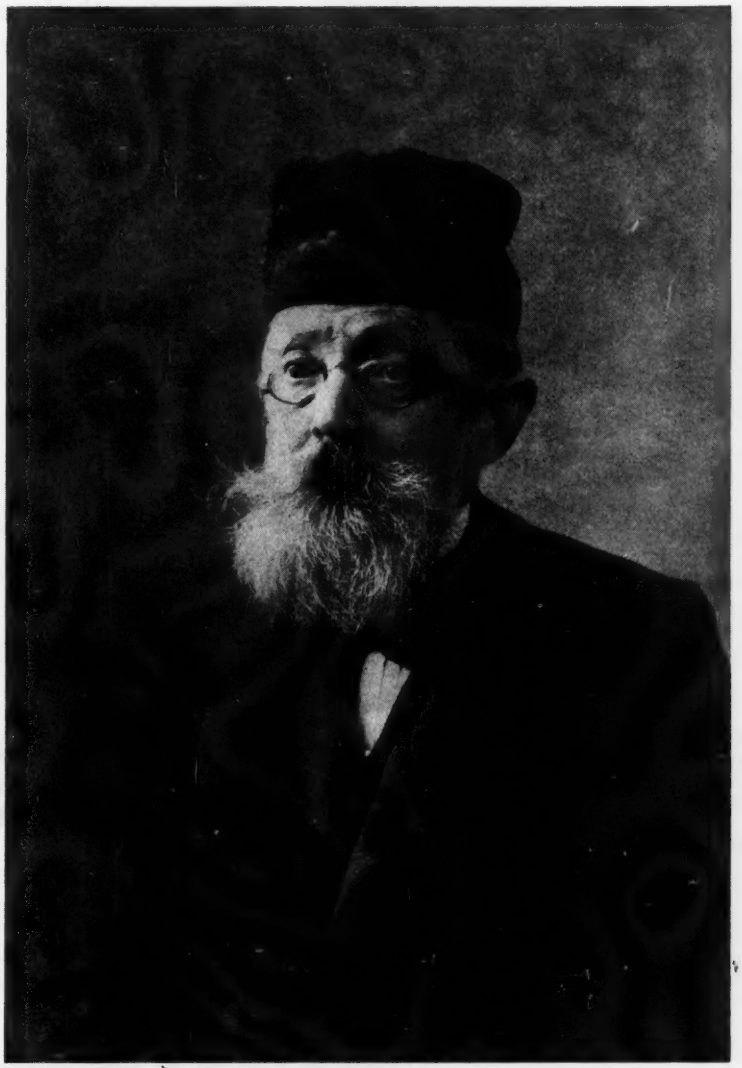

Geheimer Regierungs-Rat Professor Dr. Bernhard Tollens

(1841–1918)

(For further information, see the article, "Bernhard Tollens (1841–1918) and Some American Students of His School of Agricultural Chemistry," by C. A. Browne, on page 253.)

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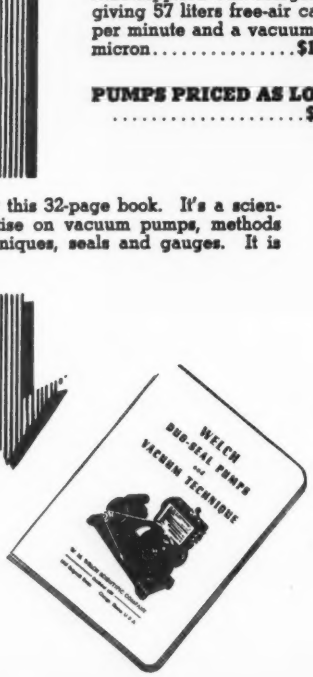

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Editor's Outlook

THIS is the time of year for stock-taking. We are busy in the storerooms of our laboratories making inventories of what is on our shelves. Why shouldn't we inventory our educational shelves, as well?

It is an uncomfortable time of the year, for student and teacher alike. In spite of (and perhaps, also, because of) the fact that examinations are staring us in the face, we are looking back over the year that has passed and becoming aware of our insufficiency. Personally, I have always held the view that it is better for a student to finish his first year's experience in general chemistry with a wholesome and honest realization of the opportunities he has missed, the things he *might* have done, than to be crammed full of the facts and jargon of the science. I believe it is really a better foundation for the next step—provided, of course, that he doesn't just let it go at that, but really uses it as a stepping-stone.

But what's sauce for the goose is also sauce for the gander, and we teachers should also be made aware of our shortcomings. Many a conscientious teacher, I imagine, makes some "New Year's resolutions" at the end of the year—and probably forgets them during the summer months. Any teacher who has the complacent feeling that his course is just what it should have been is either too far gone to be redeemed, or hasn't yet got to the stage where he can look outside himself.

Occasionally we are brought to realize, with a shock, that something is amiss. What would *you* think if you found the following note on the back of a student's examination paper?

> Sir: There's not much point in your even looking over this exam. I can tell you that there's nothing correct—hardly anything even done. You're not so sorry as I am; but I just can't make my mind function because I'm so completely tired out. Chemistry has been a desperately hard pull for me—even to get *C*'s. I took it because I thought it would be "fun" and interesting. I didn't expect anything easy; I expected to have to work. But I never expected anything like this course. I never expected that in return for hours put in, I would get nothing, or that I'd be in a complete fog the whole year. I'm wondering why a good university like this doesn't offer two sections in Chem —one for people like me whose minds don't function scientifically and who've no intention of going on; another for the others who are lucky enough to understand Chemistry.

Not that the feeling is unique, of course. Many a student has doubtless felt the same way but has not had the desperate temerity to express himself. This isn't merely the dull complaint of the poor student, anxious to rationalize his incompetence. It is the surprised observation of a girl with a good measure of scholastic ability, accustomed to success, but confronted with a subject with which she somehow could not come to mental grips. To what extent such a case is the fault of the student, and to what extent the teacher shares the responsibility, is a question often debated.

But the real question is whether this is an inevitable situation. Must we always reckon with the student of real ability who simply fails to "click" with chemistry? And shall we merely adopt the "take it or leave it" attitude? The question has had its answer, to the satisfaction of many people, in the suggestion offered—separate classes for those who want to study chemistry and those who only want to learn *about* chemistry. But suppose that isn't possible, what then? Few institutions are in a position to afford such segregation, for one reason or another.

However, the mere recognition of such a problem often carries with it the solution. We often delude ourselves—and make ourselves no end of trouble—by assuming that we must establish a curriculum, a new course, some elaborate alphabetical agency, to find a solution to a difficulty which cannot be "solved" but only appreciated.

What we need here is to keep the teacher aware of the fact that the students in his course are a composite lot of reacting units, each with its own available free energy. And how do you measure the free energy of a reacting system? By letting it work against the maximum resistance which it can just barely overcome. Then you get the maximum work output with no lost heat—which has its educational as well as physical implication.

Our whole educational system is based upon the assumption that everyone has the right to pursue knowledge to the full extent of his ability. The survival of our democracy depends upon this principle. Somehow it must also be applied to our individual courses within the system. It is hard to see how it can be accomplished by pressure from without; each teacher must provide the means by which every one of his students may obtain results according to his interests and commensurate with his ability. Beyond that, the responsibility is certainly the student's.

Yes, of course, that is a Utopian ideal. We are not told how to accomplish it, nor can we be. And that is exactly what makes the educational profession interesting and worth while. The American teacher must be able to solve his own problems; we want no regimented goose-step.

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What's Been Going On

ONE of the most important recent events in Chemical Education was the meeting of the American Chemical Society in Memphis, April 20 to 24. For several years it has been the custom at the spring meetings of the Division of Chemical Education to feature a student program. The one this year was especially successful. It began with the Student Breakfast, attended by nearly a hundred—most of them in the "young" category, but including also a considerable number of "older students," some of them prominent members of the Society.

Sixteen papers were given by students from nine different institutions, during the morning and afternoon sessions. As usual, many of these papers were on research subjects in connection with graduate work.

The general program of the Division was largely devoted to a Round Table on the Problem of Teaching Chemistry. The several papers in this symposium appear elsewhere in this number.

THE Navy Department has awarded contracts for 14 experimental gliders, four of which will be made of a wood-impregnated plastic.

Nitrogen isotope of atomic weight 15 (N^{15}) is now available in the form of ammonium nitrate from Eastman Kodak Company.

One of the outstanding developments of the year in the glass industry is said to have been the increasing application of new and special glasses in airplane manufacture.

A newly developed machine, the "rheotron" or electron accelerator, increases the speed of electrons to within one-tenth of one per cent of the speed of light. In doing this a 20,000,000-volt electron stream or X-rays of the same power are produced. This is equivalent to a beam from more than 1000 grams of radium or more than the world's available supply. A 100,000,000-volt machine is under construction.

How fats can be administered by injection into the veins in cases in which mouth feeding is impossible or undesirable is the subject of research which has been started by Dr. Alexander Brunschwig, professor of surgery at the University of Chicago, and Dr. Lucia Jordan Dunham.

Though doctors have for years been able to give venous injections of carbohydrates such as sugar for emergency nutrition, it has not been possible to supply fats by this method.

This type of "parenteral" nutrition may become of particular importance as a result of the war since it may help to make possible a balanced diet for persons whose digestive apparatus has been injured or for whom an operation may make emergency nutritional boosts necessary.

In many cases in which surgical operations are necessary, they are very hazardous because of the difficulty of providing satisfactory emergency nutrition.

To aid in conserving the nation's vital supply of pig tin, United States Steel Corporation subsidiaries are installing nine additional electrolytic tin plating production lines and six supplemental production lines for chemically treating black plate.

Electrolytic tin plate is produced by coating black plate with tin by means of an electric current passing through a solution, rather than by the conventional dipping of black plate into molten tin.

103rd MEETING OF THE AMERICAN CHEMICAL SOCIETY

DIVISION OF CHEMICAL EDUCATION

Memphis, Tennessee, April 20–24, 1942

MINUTES OF THE EXECUTIVE COMMITTEE

A MEETING of the Executive Committee was held in the Auditorium, Room D, Tuesday, April 21, at 5:00 P.M. Those present were: F. E. Brown, Chairman of the Division; A. J. Currier, Vice-Chairman; C. E. White, Treasurer; L. L. Quill, Member at Large; N. W. Rakestraw, Editor, JOURNAL OF CHEMICAL EDUCATION; and P. H. Fall, Secretary.

At the suggestion of Dr. George L. Royer, Chairman of the Division of Analytical and Micro Chemistry, a motion was made and carried that our Division coöperate with the Division of Analytical and Micro Chemistry in a symposium on "Teaching and Practice of Analytical Chemistry" to be held at the meeting in Buffalo this fall.

After discussion of the value and excellent results of the Book Exhibit which the Division was conducting at this Memphis meeting, a motion was carried that the Executive Committee endorse the recommendation of the Board of Publication that our Division conduct similar Book Exhibits at the spring meetings of the Society.

The secretary read a letter from Lloyd E. Blauch, Senior Specialist in Higher Education, Chairman, Committee on College Curriculum Adjustments, Federal Security Agency, U. S. Office of Education, in which he requested our Division to select three to five persons as a committee to make a study, and subsequently submit a report, on how the content of chemistry in the liberal arts college curriculum can be adapted, so far as may seem advisable, to aid most in the solution of the problems confronting the nation in wartime. Motion was carried that the Chairman appoint a committee to formulate a report as requested by the U. S. Office of Education Wartime Commission. The Chairman asked the Secretary to write to the following men asking them to serve on the committee:

Professor John E. Cavelti, Allegheny College, as Chairman
Professor Sidney J. French, Colgate University
Professor Roy I. Grady, College of Wooster
Professor Andrew J. Scarlett, Jr., Dartmouth College

By motion a bill of $5.00 from the American Science Teachers Association for annual dues was approved. It was suggested that we ask the Association for a report.

Some plans for the Buffalo meeting, in addition to the joint symposium with the Division of Analytical and Micro Chemistry, were discussed.

O. M. Smith, Chairman of the Committee on Examinations and Tests, made a brief report in which he stated that a copy of the 1942 Coöperative Test in Chemistry can be secured by any member of the Society upon payment of fifty cents. He also stated that his committee expects to hold a two-day meeting in Buffalo immediately preceding the Society's meeting this fall. This committee is operating entirely on funds received from the sale of tests. The budget for 1941–42 is $600. This year, for the first time, a two-hour Coöperative Test in Organic Chemistry is available. This is a new venture, Dr. Smith stated.

Dr. C. E. White, Treasurer, submitted a report.

The meeting adjourned at 6:40 P.M.

PAUL H. FALL, *Secretary*

Bernhard Tollens (1841–1918)

And Some American Students of His School of Agricultural Chemistry[1]

C. A. BROWNE *Bureau of Agricultural Chemistry and Engineering, U. S. Department of Agriculture, Washington, D. C.*

OF THE numerous minor chemical research laboratories existing in Germany since the famous one of Liebig at Giessen, the school of agricultural chemistry established by Tollens at Göttingen University in 1873 deserves mention as one of the most important. It attracted students from all parts of the world for a period of nearly 40 years. From no country, with the exception of Germany, were so many attracted as from the United States where the students of Tollens, during the productive decades following the establishment of the American Chemical Society in 1876, exerted a great influence in federal, state, and industrial fields of agricultural chemical research. Since the year 1941, which has just passed, was the one hundredth anniversary of the birth of Tollens it is fitting that we in America should pay a slight tribute to his memory at this time.

Bernhard (Christian Gottfried) Tollens (*1*) was born in Hamburg on July 30, 1841. After the customary education of the time in the local schools and gymnasium he began the practice of pharmacy, which he soon dropped in order to take up the study of chemistry at Göttingen University. After three years at this institution he obtained his doctor's degree in 1864 for an important research conducted under Fittig on the synthesis of the homologs of benzene [synthesis of Tollens and Fittig (*2*)]. After another short try at pharmacy he definitely abandoned this pursuit and devoted himself thenceforth entirely to chemistry. After a brief experience as a practical chemist in Nuremberg and Bonn he returned finally to university work, serving first as assistant to Erlenmeyer in Heidelberg and then to Wurtz in Paris. The attention resulting from his work in Paris on the production of allyl alcohol by the action of oxalic acid on glycerol (*3*) led to his appointment in 1869 as chief of the chemical laboratory at the University of Coimbra in Portugal. He resigned this position in March, 1870, after an eleven-month stay, in order to accept an appointment under Wöhler at Göttingen, where two months later he passed his habilitation examination as *privatdozent*. In 1873 he was made professor and director of the chemical laboratory of the Agricultural Institute of Göttingen, succeeding Wilhelm Wicke (1822–71), who first established an independent laboratory for agricultural chemical research at Göttingen in 1853 (*4*). Tollens had now come to the end of his "Wanderjahre" and entered upon the position which he was to occupy for the next 38 years until his retirement in 1911 at the age of 70.

[1] Presented before the Division of the History of Chemistry at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 22, 1942.

The Agricultural Institute of Göttingen had already become famous through the work of its Director, Wilhelm Henneberg (1825–90), a pupil of Liebig and the world's leading authority at the time on animal nutrition (*5*). It was Henneberg who in 1863 introduced the present scheme of cattle feed analysis with its loosely defined concepts of crude fiber and nitrogen-free extract. These terms, designed to cover the entire carbohydrate content of feeding stuffs (the crude fiber or the assumed indigestible fraction and the nitrogen-free extract or the assumed digestible part), were recognized by Henneberg at the time of their introduction to be imperfect and only conventional expressions; yet for want of something better they have continued in constant use down to the present time. It was to the discovery of the exact chemical nature of these unknown carbohydrate constituents of crops that Tollens turned his attention immediately after assuming the duties of his new office and, when he had terminated his work in this field at the time of his retirement, his school of chemistry had succeeded not only in largely unraveling the nature of the intricate mixture of hexosans, pentosans, methylpentosans, and other constituents that make up the crude fiber and nitrogen-free extract complex of plants, but also in elaborating methods for their determination—methods that are still standard in our textbooks of agricultural analysis (*6*). There is not space to give the interesting details of Tollens' contributions to this subject in the present paper, the chief object of which is to mention the influence exercised by Tollens upon agricultural chemistry in the United States through a number of his American students and to give an account of Tollens' personality and method of teaching.

AGRICULTURAL CHEMICAL LABORATORY, AGRICULTURAL INSTITUTE OF GÖTTINGEN UNIVERSITY

Nearly all of Tollens' first American students were graduates of the Massachusetts Agricultural College at Amherst. This was largely owing to the influence of Dr. Charles Anthony Goessmann (1827–1910), a Ph.D. of Göttingen in 1852, Professor of Agricultural Chemistry at Massachusetts Agricultural College from 1868 until his retirement in 1908, and a strong advocate of Tollens' school of postgraduate agricultural chemical research. The following graduates of Goessmann, who obtained their Ph.D. degrees under Tollens, are named with a brief record of the dates of their degrees and important positions:

Charles Wellington (1853–1926), B.S., Massachusetts Agricultural College, 1873; Assistant Chemist, U. S. Department of Agriculture, 1877–82; Ph.D., Göttingen, 1885; Associate Professor of Chemistry, Massachusetts Agricultural College, 1885–1907; Professor of General and Agricultural Chemistry, Massachusetts Agricultural College, 1907–26.

Horace Edward Stockbridge (1857–1930), B.S., Massachusetts Agricultural College, 1878; Assistant Chemist, U. S. Department of Agriculture, 1880; Ph.D., Göttingen, 1884; Instructor of Chemistry, Massachusetts Agricultural College, 1881; Associate Professor of Chemistry and Geology, 1884–85; Professor, Imperial College of Agriculture, Sapporo, Japan, 1885–89; Chief Chemist, Japanese Government, 1887–89; Director, Indiana Experiment Station, 1889; President, North Dakota Agricultural College and Director, North Dakota Experiment Station, 1890–94; Director, Farmers Institute, Florida, 1897–1905; Editor, *Southern Ruralist*, 1906.

John Hosea Washburn (1859–1932), B.S., Massachusetts Agricultural College, 1878; Professor of Chemistry, Storrs Agricultural School, Connecticut, 1883–87; Ph.D., Göttingen, 1889; President and Professor of Agricultural Chemistry, Rhode Island College of Agriculture and Mechanic Arts, 1889–1902; Director, National Farm School, Doylestown, Pennsylvania, 1902–17.

Homer Jay Wheeler (1861–), B.S., Massachusetts Agricultural College, 1883; Assistant Chemist, Massachusetts Agricultural Experiment Station, 1883–87; Ph.D., Göttingen, 1889; Chemist, Rhode Island Agricultural Experiment Station, 1889–1907; Director, Rhode Island Agricultural Experiment Station, 1901–12; Acting President, Rhode Island College of Agriculture and Mechanic Arts, 1902–03; Chief Agronomist, American Agricultural Chemical Company, 1912–31.

Winthrop Ellsworth Stone (1862–1921), B.S., Massachusetts Agricultural College, 1882; Assistant Chemist, Massachusetts Agricultural Experiment Station, 1884–86; Ph.D., Göttingen, 1888; Chemist, Tennessee Agricultural Experiment Station, 1888–89; Professor of Chemistry, Purdue, 1889–92; Vice-President, Purdue, 1892–1900; President, Purdue, 1900–21.

Joseph Bridgeo Lindsey (1862–1939), B.S., Massachusetts Agricultural College, 1883; Assistant Chemist, Massachusetts Agricultural Experiment Station, 1883–85; Chemist, L. B. Darling Fertilizer Company, 1885–89; Ph.D., Göttingen, 1891; Chemist, Massachusetts Agricultural Experiment Station, 1892–1932; Vice-Director, Massachusetts Agricultural Experiment Station, 1907–32; Professor of Agricultural Chemistry, Massachusetts Agricultural College (name changed to Massachusetts State College in 1931), 1911–32.

Edward Rawson Flint (1864–1926), B.S., Massachusetts Agricultural College, 1887; Assistant Chemist, Massachusetts Agricultural Experiment Station, 1887–90; Ph.D., Göttingen, 1892; Assistant Professor of Chemistry, Massachusetts Agricultural College, 1893–99; M.D., Harvard, 1903; Professor of Chemistry, University of Florida, 1904–17; Administrative Assistant, Office of Experiment Stations, U. S. Department of Agriculture, 1917–26.

Edwin West Allen (1864–1929), B.S., Massachusetts Agricultural College, 1885; Assistant Chemist, Massachusetts Agricultural Experiment Station, 1885–88; Ph.D., Göttingen, 1890; Assistant, Office of Experiment Stations, U. S. Department of Agriculture, 1890–93; Assistant Director, Office of Experiment Stations, 1893–1915; Chief, Office of Experiment Stations, 1915–29; Editor, "Experiment Station Record," 1895–1924.

As a result of the success of these first American students who obtained their postgraduate training under Tollens, the belief was established that this was one of the best doors to advancement for those who desired to specialize in agricultural chemistry. The tide of students in this field continued to flow toward Göttingen from the United States, the graduates of other American institutions than Massachusetts Agricultural College now taking part in the movement, however. The impelling influence in this second migration was Tollens' student, Dr. Edwin West Allen, who, in his office of Vice-Director and Director of the Federal Office of State Experiment Stations, by his wise counsel helped many a young aspiring agricultural chemist on the road to success. Of these later Americans who obtained their doctorates for postgraduate work under Tollens may be mentioned:

Peter A. Yoder (1867–1929), A.B., Indiana University, 1894; Instructor, Chemistry, Indiana University, 1894–96; Ph.D., Göttingen, 1901; Associate Chemist, Utah Agricultural Experiment Station, 1901–05; Director and Chemist, Utah Agricultural Experiment Station, 1905–07; Research Chemist, Louisiana Sugar Experiment Station, 1908–10; Assistant Chemist, U. S. Bureau of Chemistry, 1910–13; Sugar Cane Technologist, U. S. Bureau of Plant Industry, 1913–29.

George M. Tucker (1869–1940), B.S., Rhode Island College of Agriculture and Mechanic Arts, 1894; Assistant Agronomist, Rhode Island College of Agriculture and Mechanic Arts, 1894–97; Ph.D., Göttingen, 1899; Manager, Rubber Plantation, Mexico, 1900–02; Instructor, Agronomy, University of Missouri, 1902–04; Editor on Field Crops, Office of Experiment Stations, U. S. Department of Agriculture, 1904–13.

William Edward Barlow (1870–1939), A.B., Cambridge, 1895; Ph.D., Göttingen, 1903; Associate Professor, Industrial Chemistry and Metallurgy, Virginia Polytechnic Institute, 1904–06; Dean, Graduate Department, Virginia Polytechnic Institute, 1908–39.

Charles Albert Browne (1870–), A.B., Williams, 1892; Commercial Analyst, New York City, 1892–94; Instructor of Chemistry, Pennsylvania State College, 1895–96; Assistant Chemist, Pennsylvania Agricultural Experiment Station, 1896–1902; Ph.D., Göttingen, 1901; Research Chemist, Louisiana Sugar Experiment Station, 1902–06; Chief, Sugar Laboratory, U. S. Bureau of Chemistry, 1906–07; Chemist of New York Sugar Trade, 1907–23; Chief, U. S. Bureau of Chemistry, 1923–27; Chemist, U. S. Department of Agriculture, 1927–40.

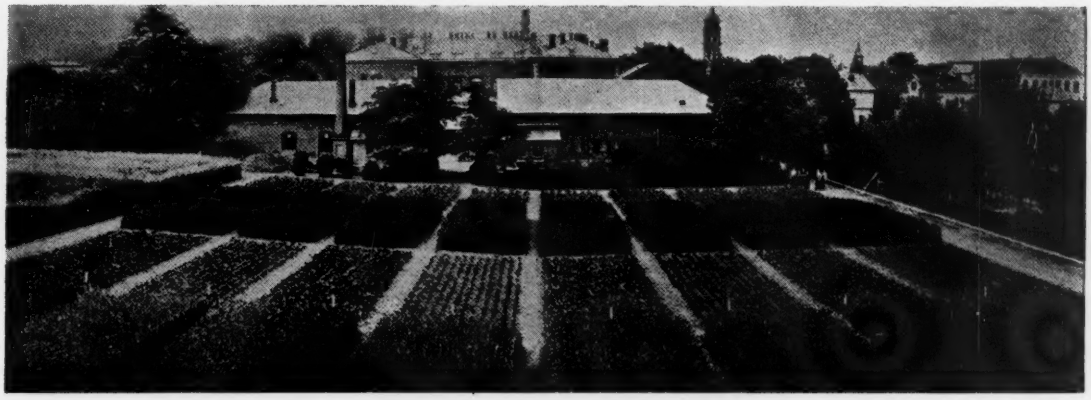
John Andreas Widtsoe (1872–), B.S., Harvard, 1894; Professor of Chemistry, Utah Agricultural College, 1894–98; Ph.D., Göttingen, 1899; Director, Utah Agricultural Experiment Station, 1900–05; President, Utah Agricultural College, 1907–16; President, University of Utah, 1916–21; Council, Twelve Apostles Latter Day Saints Church, 1921– .

Walter Beal Ellett (1874–), B.S., Virginia Polytechnic Institute, 1894; Assistant Chemist, Virginia Agricultural Experiment Station, 1896–1901; Ph.D., Göttingen, 1904; Chemist, Virginia Agricultural Experiment Station, 1906– ; Professor, Agricultural Chemistry, Virginia Polytechnic Institute, 1915– .

Several of Tollens' students who were not Americans held important positions for a time in the United States. Among these may be mentioned Dr. William E. Cross of England who obtained his Ph.D. under Tollens in 1910. He was chemist of the Louisiana Sugar Experi-

ment Station from 1910–14 and is now Director of the Agricultural Experiment Station at Tucuman, Argentina.

Horace Everett Lincoln Horton (1864–1934). Attended Harvard, 1884–87; worked with Tollens and took his lectures about 1888–89; was later agricultural chemical expert of the American Steel and Wire Company, Chicago.



AGRICULTURAL INSTITUTE OF GÖTTINGEN UNIVERSITY
Experimental field-plots in foreground; tower of Jacobi Kirche in distance

A number of Americans who obtained their doctorates at Göttingen took agricultural chemistry under Tollens only as a minor Ph.D. requirement. Among these may be mentioned:

Arthur Amber Brigham (1856–1938), B.S., Massachusetts Agricultural College, 1878; Professor of Agriculture, Imperial College of Agriculture, Sapporo, Japan, 1889–93; Ph.D., Göttingen, 1896; Professor of Agriculture, Rhode Island College of Agriculture and Mechanic Arts, and Director, Rhode Island Agricultural Experiment Station, 1898–1901.

Edwin Broun Fred (1887–), B.S., Virginia Polytechnic Institute, 1907; Ph.D., Göttingen, 1911; Bacteriologist, Virginia Agricultural Experiment Station, 1911–13; Professor of Bacteriology, University of Wisconsin, 1918– ; Dean, Graduate School, University of Wisconsin, 1935– .

In addition to the chemists who majored or minored under Tollens there were many American postgraduates who worked in his laboratory or heard his lectures, but with no intention of qualifying in agricultural chemistry as a major or minor degree subject. To this miscellaneous class belonged some who were majoring at Göttingen in organic chemistry under Professor Otto Wallach, or in physical chemistry under Professor Walther Nernst, or in some other branch of science, and wished to broaden their knowledge with an extra chemical course. Other students of this group were simply "birds of passage" who, on sabbatical leave, or a random tour of study, were spending a semester here and there at different universities. Tollens always had more of these occasional students than of regular "doctoranden." The following Americans are named among the large number who belonged to this incidental class:

Henry Hill Harrington (1859–1939), B.S., Mississippi State College, 1883; Professor of Chemistry, Texas Agricultural College, 1888–1906; President of same, 1905–07; Director, Texas Agricultural Experiment Station, 1906–11; worked one semester with Tollens in 1904.

Frederic Coffin Weld (1864–1921), A.B., Harvard, 1886; worked with Tollens and took his lectures in 1888 and 1889; on returning to America was chemist with the Merrimac Manufacturing Company, Avery Chemical Company, Lowell Bleachery, Amoskeag Manufacturing Company, etc.

Bennett Battle Ross (1864–1930), A.B., Alabama Polytechnic Institute, 1881; LL.D., Southern, 1917; Professor of Chemistry, Louisiana State University, 1887–93; Professor of Chemistry, Alabama Polytechnic Institute, and State Chemist, Alabama, 1893–1930; Dean, Department of Science, 1921–30; worked with Tollens and took his lectures in 1900–01.

Fritz Wilhelm Woll (1865–1922), M.S., University of Wisconsin, 1886; Ph.D., 1904; Chemist, Wisconsin Agricultural Experiment Station, 1893–1922; Professor, Animal Nutrition, University of California, 1913–22; heard Tollens' lectures in 1901.

Cyril George Hopkins (1866–1919), B.S., South Dakota Agricultural College, 1890; Ph.D., Cornell, 1898; Chemist, Illinois Agricultural Experiment Station, 1894–1919; Professor of Agronomy, University of Illinois, 1900–19; worked with Tollens and heard his lectures in 1899–1900.

Meade Ferguson (1869–), B.S., Virginia Polytechnic Institute, 1896; Ph.D., Göttingen, 1902; Associate Professor, Virginia Polytechnic Institute, 1902–08; later bacteriologist, Virginia State Health Department and Virginia Department of Agriculture; heard Tollens' lectures one semester.

George Carl Spencer (1870–), B.S., Worcester Polytechnic Institute, 1898; Ph.D., Göttingen, 1913; Instructor, Chemistry, Lowell Textile School, 1898–1907; Chemist, U. S. Department of Agriculture, 1907–10, 1913–31; worked with Tollens and heard his lectures one semester in 1911; took his Ph.D. under Wallach.

William Jay Hale (1876–), A.B., Harvard, 1898; Ph.D., 1902; taught chemistry at University of Michigan, 1904–19; Director, organic chemistry research, Dow Chemical Company, 1919–34; worked with Tollens and heard his lectures, summer semester, 1903.

It is seen that the list of Americans who obtained their degrees under Tollens, or who only took his courses, is a long one. No other European school of agricultural chemistry attracted so large a number of American students as his, not even the famous one established by Liebig at Giessen, and the record of these students after their return to America, as presidents of agricultural colleges, as directors and chemists

of state agricultural experiment stations, as professors of agricultural chemistry, as experts in the U. S. Department of Agriculture, as editors of agricultural journals, and as leaders in other fields of agricultural research and education is one that stands without an equal. The record of Tollens' students in Great Britain, the British Colonies, Netherlands, the Dutch Colonies, Russia, and Japan is also exceedingly high.

PROFESSOR TOLLENS WITH A GROUP OF HIS RESEARCH STUDENTS, MARCH, 1901

Beginning with Tollens and going clockwise around the table the persons are:

Professor B. Tollens
Dr. A. Hugershoff, Assistant
Al. Nastukoff, Russia
Kintaro Oshima, Japan
G. Derewjamco, Russia
A. Klütschareff, Russia
J. Sack, Holland
G. Bouygues, France
C. A. Browne, United States
C. M. van Marle, Holland
B. B. Ross, United States
A. J. Gibson, Australia
B. Briese (standing in rear), laboratory janitor
M. E. Wolvekamp, Java
R. Hauers, Germany
F. Peim (seated at right), Russia

There are two explanations for the great popularity and influence of Tollens' school of agricultural chemistry in America during the thirty-year period between 1880 and 1910. First: in the early 1880's, coincident with the state experiment station movement which culminated in the passage of the Hatch Act of 1887, there was a sudden extensive demand for agricultural chemists in all parts of the country. Professor Charles Goessmann of Massachusetts Agricultural College, who for six years had been a student and *privatdozent* at Göttingen University, was among the first to foresee the significance of this movement. He urged his students to prepare themselves for the opportunities that were bound to arise by taking postgraduate courses in agricultural chemistry at the Göttingen Agricultural Institute with the advantages of which he was well acquainted. The readiness with which Goessmann's students worked into important positions in the United States after their return from Göttingen justified the correctness of his foresight and advice.

The second explanation for the flow of American students to the Agricultural Institute of Göttingen was the great value of the instruction given there by Tollens and his colleagues, all of whom were leaders in their respective fields. In the flourishing period of this Institute it is doubtful if there was any place in the world where a better general training could be acquired in the fundamentals of agricultural science. There were several departments, with independent research laboratories in the Institute building, such as field crops, animal nutrition, dairying, and agricultural chemistry. Each of these divisions had its own staff of chemists so that Tollens was not burdened with analytical work for other units but was left free to pursue his own independent lines of research without outside interruptions. Friendly collaboration existed between the different divisions, the results of their research activities appearing in the official publication of the Institute, the *Journal für Landwirtschaft*, of which Tollens was Editor-in-Chief for 21 years. It is in this journal, in the *Berichte* of the German Chemical Society, and in the printed dissertations of his students that the results of Tollens' agricultural chemical investigations are chiefly to be found.

The scientific atmosphere of Tollens' laboratory was most cosmopolitan. In addition to German, conversations could be heard in English, Dutch, French, Russian, and other languages. Tollens was a good

linguist and conversed with newcomers in English or French until they had gained a command of German. The accompanying photograph taken in March, 1901, of one of Tollens' more advanced postgraduate classes (in which are seen students from Russia, Japan, Holland, France, the United States, Australia, the Dutch East Indies, as well as from Germany) is illustrative of the general good will that prevailed among the nations of the world at that time. Cordial appreciation of the accomplishments of each country characterized the members of this group. What a contrast between the peaceful Germany of 1900 when the entire world looked up to her in friendly recognition of her high standing in science and education and the berserk Germany of 40 years later!

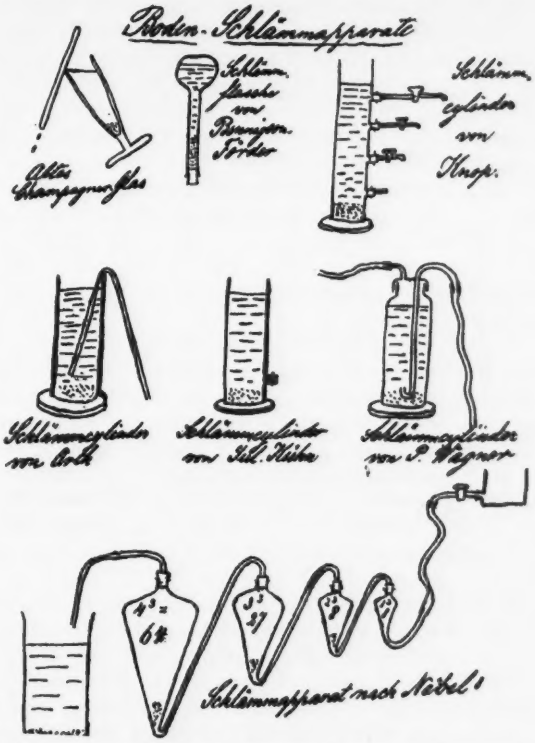
The writer knows few chemistry teachers who were so solicitous as Tollens about helping students. Hectographed and mimeographed outlines of his courses, prepared in his neat handwriting with sketches of apparatus, tabulations, and other elaborate details, were distributed among his hearers before each lecture. These outlines (see the illustration) were of the greatest service for reviewing his lectures in preparation for an examination.

Tollens was a man of small stature ("drei Käse hoch" to use a facetious comparison of some of his disrespectful students) and during lecturing was obliged to stand on a low platform behind the demonstration table. When he entered the lecture room, wearing his customary embroidered skull cap, his students would shuffle their feet by way of greeting. He acknowledged the salutation with a bow and then after a brief résumé of the previous lecture would begin elucidating the topic of the day.

One of the great events at the Göttingen Agricultural Institute was Tollens' annual lecture on guano. The lecture table was crowded with bottles of this famous product from the South Seas and with mounted specimens of the pelicans and other birds that produced it. Toward the close of the lecture the little Geheimrat, as every one called him, would recite with shrill voice, and a wave of his hand toward the pelicans, several lines from the famous "Guano Lied." "Ja, meine Herren! Die Vögel sind all Philosophen. Kein einz'ger versäumt seine Pflicht." When I revisited Göttingen thirty years after hearing this lecture I saw again in the agricultural chemical museum the same stuffed pelicans and the same guano bottles, still bearing the neatly inscribed labels in Tollens' familiar handwriting. Former recollections were awakened and once more I saw before me the scene in the old lecture room.

When his morning lecture was over Tollens would descend by a private spiral staircase to his private laboratory where he would exchange his formal lecture-room frock coat for an ordinary jacket. My first conversation with Tollens occurred at the foot of the aforesaid staircase while he was performing this change of raiment and I was somewhat surprised to note that he wore not a "Hemd" but a "Vorhemd" or what is vulgarly termed in English a "dicky." Tollens was a very matter-of-fact man and showed not the slightest embarrassment over this disclosure, as he went on to tell me that "doctor-making isn't done in Göttingen until you have first passed a Verbandsexamen." This "Verbandsexamen" was a series of preliminary tests in qualitative analysis, use of the blow pipe, gravimetric and volumetric analysis, and organic preparation work, which were required of all students desiring to work for a degree. These practical tests were then followed by a two-hour quiz. The purpose of the "Verbandsexamen" was to weed out incompetent students at the very beginning. It was a very time-consuming affair and in my own case was found to be far more severe than the final oral examination for the doctor's degree.

Tollens showed the same attention to helping his students in their laboratory operations as in the preparation of synopses for their lectures. For beginner and for advanced research worker, he showed the same solicitude and attention to detail, whether it was in blowing a glass bulb, in trying out a new color reaction, in purifying a precipitate, or in following the mutarotation of a sugar. He enjoyed making calculations on



HECTOGRAPH SHEET OF DIFFERENT TYPES OF SEDIMENTATION APPARATUS, DRAWN BY TOLLENS FOR ILLUSTRATING A LECTURE ON SOILS

the pages of his students' notebooks and took pleasure in discussing questions of historic chemical interest. I recall how at the laboratory blackboard he showed a group of us one day that just as good results could be

calculated by the old chemical equivalents as by the modern atomic weights. He was particularly helpful to backward students, not only performing much of

Verbandszeugniss.

Herr Edw. A. Browne aus North Adams Mass. V. St. Amerika

Vorbildung: Williams College in Williamstown Mass. V. St. Am.

hat die Verbandsprüfung in folgenden Fächern bestanden:

Prüfungsgegenstand	Examinator	Hochschule	Datum	Art der Prüfung
Praktische Prüfung Unorganische Chemie Analytische Chemie	Tollens	Göttingen	16 Juli 1900	mf
Organische Chemie				

Angefertigt und in das Register eingetragen am 17 Juli 1900

Unterschrift des ausrufertigenden Laboratoriumsvorstandes:

Dr. H. Tollens
Prof.
Dir. d. agricultur-chemischen Versuchsstation d. Königreichs Hannover

"VERBANDS" CERTIFICATE FOR PASSING EXAMINATIONS IN PRACTICAL, INORGANIC, ANALYTICAL, AND ORGANIC CHEMISTRY, WITH SIGNATURE OF TOLLENS

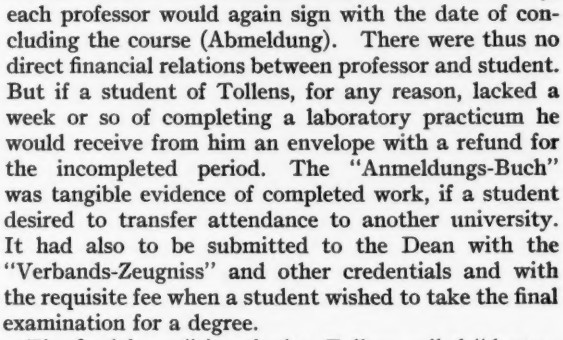
their laboratory work but even writing up their results for publication. And when such work was published in the *Berichte* or other journal the name of the student always preceded his own as author. Students were not always appreciative of these little acts of kindness and sometimes tried his patience by such practical jokes as hiding his little skull cap. On such occasions he sought Briese, the faithful laboratory "Diener," of whom he inquired plaintively, "Herr Briese, wo ist meine Mütze? Ohne die Mütze kann ich nicht arbeiten." But Tollens never showed resentment at these liberties and when the time came for closing at noon or evening his cheerful voice could be heard wishing his boys a "gesegnete Mahlzeit" or "gute Nacht" as the case might be.

Tollens gave instruction not only by lectures and laboratory practice but also by excursions when he took groups of his students to beet sugar factories, starch factories, breweries, and distilleries for the purpose of letting them observe some of the practical applications of his agricultural chemical teaching. The superintendents of these establishments always welcomed him on these visits since it gave them an opportunity for getting his expert advice on some of their factory problems.

The students of the Göttingen Institute had a society known as the "Landwirtschaftlicher Verein" in whose scientific gatherings (where plenty of beer and tobacco were consumed) the professors of the Institute frequently took part. On such occasions a student would read a paper which was then discussed by his companions and the professors. Tollens enjoyed participation in these student convivial gatherings. At a very large "Kneipe" held in Göttingen on July 31, 1900, by the chemistry students of all the different university schools to commemorate the hundredth anniversary of Wöhler's birth, Tollens, Wallach, Nernst, and other leading members of the chemical faculty took part. There was much singing of student songs, drinking of salamanders, and delivering of burlesque toasts. Tollens caused much laughter by proving that the Egyptians were acquainted with several forms of nitrogen. They not only produced ammonia at the temple of Jupiter Ammon but they also made the *pyramids*.

Tollens was scrupulously fair in all his dealings with students. When we had inscribed the courses which we wished to take in our "Anmeldungs-Buch" at the beginning of each semester we reported to the Quästur of the University to whom we paid the fees. He would mark the amounts as paid in the book, which we would then show to each professor who would sign his name with the date of beginning the course (Anmeldung). At the close of the semester we would again present our books when, if our attendance had been satisfactory, each professor would again sign with the date of concluding the course (Abmeldung). There were thus no direct financial relations between professor and student. But if a student of Tollens, for any reason, lacked a week or so of completing a laboratory practicum he would receive from him an envelope with a refund for the incompleted period. The "Anmeldungs-Buch" was tangible evidence of completed work, if a student desired to transfer attendance to another university. It had also to be submitted to the Dean with the "Verbands-Zeugniss" and other credentials and with the requisite fee when a student wished to take the final examination for a degree.

The final formalities of what Tollens called "doctor-making" marked the conclusion of our associations



PAGE OF ANMELDUNGS-BUCH, GÖTTINGEN UNIVERSITY, SUMMER SEMESTER, 1901, WITH ENTRIES AND FEES FOR COURSES, RECEIPT OF THE QUESTOR, AND SIGNATURES OF PROFESSORS

with the little "Geheimrat." If our laboratory researches had yielded results of sufficient merit, he would ask us to prepare a draft of our dissertation which he would then go over with us line by line, expanding here and deleting there, until the final result was satisfactory. Instances were known where Tollens, out of the kind-

ness of his heart toward a backward student, would rewrite the entire dissertation. These editorial conferences with Tollens, in the quiet seclusion of his home on the Theaterplatz of Göttingen, were delightful contacts. He would bring out the cigars and when these were lighted proceed to scrutinize each sentence of the dissertation. If by any chance he should rewrite a passage, he would glance at the student out of the corner of his eye with a gentle look of reproach. When the session was completed he would change the subject and talk about some of his past experiences or inquire about conditions in the United States, which he had never visited. If the candidate expressed anxiety about the results of the final examination, he would reassure him by saying he would be given suggestive hints in case of difficulty.

At the designated time the candidate in frock coat, white gloves, and high silk hat met the Dean and examining committee at the Aula of the University where he was examined orally one hour by Tollens, if his major subject was agricultural chemistry, and one-half hour by each of the professors for his minor subjects. The candidate then withdrew while his case was being debated; he was then readmitted to the examining room where the Dean announced the decision of the committee. If he was successful in passing the examination there was a general congratulation with handshaking. On leaving the building the newly-made doctor was greeted by a group of awaiting friends who, having soon to undergo the same ordeal, were inquisitive about the nature of the questions asked.[2]

My last conversation with Tollens occurred in June, 1906, while I was passing through Göttingen on my way to Bremen to take the steamer for New York. Tollens had just received a large volume of the collected researches of Emil Fischer and when we had completed an examination of its contents he closed the book with the exclamation, "Es ist ganz merkwürdig was der Mench geleistet hat!" He was always generous in his praise of Fischer's accomplishments.

On retiring from his professorship in 1911 at the age of 70, Tollens received congratulatory letters from his former students in all parts of the world. Seventy-nine of them, including many Americans, presented him with a testimonial consisting of an immense album with photographs of his former students, a large table, two leather upholstered chairs, a silver jardiniére, framed pictures of his laboratory, a portfolio, and other gifts. His simple response to this evidence of affection was characteristic:

"Dass die Herren auf diese Weise meiner gedacht haben, hat mich aufs höchste überrascht, denn ich habe doch nur meine Pflicht getan, und, dass ich das Alter von 70 Jahre erreicht habe, ist doch nicht mein Verdienst sondern eine Gnade von oben."

Tollens devoted the first years of his retirement to literary work; he issued several scientific articles that awaited publication, brought out a new third edition of his "Kurzes Handbuch der Kohlenhydrate" and wrote several appreciative obituary sketches of departed friends. The last four years of his life during World War I were spent in sorrow. He was loyal to his country and in letters to his old students predicted a victory for Germany. When privations came he contributed to the relief of distress, so far as his resources and strength permitted. The citizens of Göttingen, with whom in better days he used to make the customary afternoon promenade about the city's walls, now saw the frail familiar figure of the little Geheimrat helping with the delivery of their mail. He was spared the anguish of seeing Germany go down in final defeat, for he died on January 31, 1918, at the age of $76\frac{1}{2}$ years.

After the World War foreign students seldom attended the Göttingen School of Agricultural Chemistry. The passing of Tollens may therefore be said to mark the close of an epoch. He was one of the last representatives of the old-school Germany university professor—a kindly type of teacher that is now almost extinct.

[2] It was typical of the international character of Tollens' school of agricultural chemistry that the last student to complete a thesis under his direction was Venkata Rao, a native of India. Although stricken with tuberculosis he rallied sufficiently to take the doctoral examination, which he passed successfully, but the effort was too great for his enfeebled body and he died soon afterward—a victim of the harsh German climate. Tollens with characteristic kindness published an abstract of Rao's dissertation, "Über die Bestimmung der Zellulose mittels Salpetersäure," in the *J. Landw.*, **61**, 237 (1913), to which he added an affectionate tribute to his student's memory.

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MEETING OF THE SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION

THE fiftieth annual meeting of the Society for the Promotion of Engineering Education will be held in New York City at Columbia University on Saturday and Sunday, June 27 and 28. The meeting will consider "The Engineering College at War."

Round Table on the Problem of Teaching Chemistry

The Problem of Chemistry in General Education[1]

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TRADITIONALLY, the primary function of chemistry instruction has been to train specialists capable of performing the activities of chemical nature necessary for the maintenance of industry and commerce, and of advancing the frontiers of knowledge in both the theoretical and the applied aspects of chemistry and the related fields such as physics, engineering, agriculture, biology, and medicine. In the history of chemistry instruction there have been many changes in both content of the courses and methods of instruction. These changes were caused by the rapid and marked expansion in chemical knowledge with the resulting changes in the concepts and principles, by the increase in the variety of occupations requiring training in chemistry, and by changes in our educational system. During all these changes in chemistry instruction, however, the objective has remained fairly clear, namely to train specialists. While many problems are still with us, it is a matter of record that chemistry teachers have proved equal to the demands made upon them. The high state of development of American chemistry is a convincing evidence of the success of chemistry instruction.

In recent years, however, people from many fields, including chemistry, have been making a persistent demand upon chemistry teachers (as well as the other science teachers) to consider and assume another important function, namely, instruction for purposes of general education. Largely due to the impact of science, society is being radically transformed and is becoming increasingly complex. Problems of enormous magnitude are being created, such as production and control of power, production of materials, and conservation and utilization of natural resources. These problems must be solved if society is to survive. It is true that these problems cannot be solved by knowledge of chemistry alone, but it is equally true that an understanding of the chemical principles and facts that lie at the roots of these problems can do much to further their solution. At least it might be argued that a lack of such an understanding is likely to hinder the rational solution of these problems. Chemistry teachers are expected to contribute to the solution of these problems not only by disseminating the pertinent information, but also by training the average citizen in the intellectual methods by which problems may be solved. Thus chemistry, which is playing an important role in changing the material aspects of our environment, is asked to assume a greater responsibility in directly shaping the intellectual life of society.

Before considering the problem further one might ask whether at the present time it is wise to assume such an added responsibility. We are a nation at war, and the facilities of the chemistry departments are strained to the breaking point by the demand to train technically competent individuals who will take part as quickly as possible in the war effort. Moreover, most teachers of chemistry are preoccupied either with war research or with special activities for which their special training and abilities qualify them. Beyond doubt, the emergency activities must take precedence, but this does not decrease the importance of the problem of general education. More than ever before, the average citizen will be asking himself questions which require an understanding of chemistry. Questions such as the following are already with us: Why is there a shortage of tin? Can a substitute be found? Why is there a shortage of rubber? Will synthetic rubber relieve the situation? What are incendiary bombs? What are war gases? Under what conditions can they be used effectively? What precautions should be taken against them? Moreover, the average citizen will be asked to pass judgment on questions of national policy, such as: Shall we maintain a synthetic rubber industry to insure self-sufficiency? Shall we build large stocks of essential raw materials not available within our borders? The kind of judgment he will make will depend to a large measure upon the understanding of the chemical facts and principles involved. Training in the analysis and understanding of such

[1] Presented at the Round Table on the Problem of Teaching Chemistry, sponsored by the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

problems is therefore more necessary now than it has been at any time in the past.

In returning to the consideration of the problem, we find two aspects that have forced themselves to the attention of chemistry teachers. One aspect is the danger of overspecialization. The increase in the complexity of all fields of knowledge would seem to make it imperative for the specialist to start his training early and to devote practically all his time to mastering the subject matter and to developing the special skills and technics of his field. As a consequence he finds little or no time to devote to understanding the relation of chemistry to the other sciences, to obtaining the proper historical perspective of the development of his science, to appreciating the humanistic values of his science, or to considering the social implications. The result is that he has not developed the breadth which a leader in society should have. This deficiency can prevent the specialist from achieving the success which he might otherwise attain. But what is even more detrimental to society is that if he succeeds despite his lack of well-rounded development, he attains a position of influence and power in his community without the corresponding breadth for the proper use of this power.

The second aspect of the problem is the presence of non-specializing students in courses in high-school and introductory college chemistry. Indeed, it is this aspect that called the problem to the attention of most chemistry teachers, and which is pressing for consideration. We find an increasing number of students taking chemistry not with the intention of specializing but for the discipline which a study of science gives and for a better understanding of the chemical aspects of our environment. At first many teachers, either unwilling or unable to comprehend the deeper significance of the problem, took the position that "chemistry is chemistry" and made no attempt to meet the needs of the non-specialist.

An increasing number of teachers, however, have given serious thought to the problem and have expressed themselves on several occasions. In a questionnaire recently sent out by a committee of the American Association for the Advancement of Science,[2] a number of direct questions were put to chemistry teachers. Three of the most pertinent questions together with the replies of 212 teachers are as follows:

Do you consider that the conventional introductory college chemistry course as represented by a majority of current textbooks and laboratory manuals:

	Replies		
	Yes	*No*	*Uncertain*
1. Is in general satisfactory for the non-specializing student?	31%	58%	10%
2. Is more appropriate for students who later specialize in chemistry than for those who do not?	72%	16%	6%
3. Could be significantly improved for the non-specializing student?	65%	17%	18%

If these replies are representative of the opinion of chemistry teachers, it is evident that the majority feel that the problem of general education is real, is capable of solution, but has not been solved by the present courses.

The problem of general education may be broken down into a number of smaller problems which in turn must be investigated. Some of these problems may be attacked by critical analysis directed toward clarification; others might require studies in the form of questionnaires, library research, and the like; while still others might require actual trial in the classroom. It is the purpose of this paper to raise and define these problems, and offer some suggestions that might help in their solution. It is hoped that a consideration of any one of the smaller problems would lead to tentative conclusions and throw some light on the entire problem.

One of the problems that confronts us at the outset is, "What is meant by general education?" This is a question that has not been adequately answered, and indeed it is the kind of question that cannot be answered once for all but must be answered anew as conditions change. Several national societies are already considering this question, including the American Association for the Advancement of Science, the National Education Association, and the Progressive Education Association. The last mentioned organization has formulated the following definition of general education:

> The purpose of general education is to meet the needs of individuals in the basic aspects of living in such a way as to promote the fullest possible realization of personal potentialities and the most effective participation in a democratic society.[3]

If we are to expand this into a really practical statement we need the united efforts of educators, scientists, and philosophers. The American Chemical Society is already coöperating with at least the first of these groups.

The second problem that arises is, "What can chemistry contribute to general education?" Chemistry teachers have already given a considerable amount of thought to this problem. On several occasions, questionnaires have been sent to teachers, asking for their judgment on this point. A fair summary of the replies to these questionnaires is the following list of objectives in the order of decreasing frequency and weight.[2]

1. Develop ability to do critical thinking.
2. Make students familiar with the facts, principles, and concepts of chemistry.
3. Show how the discoveries of science have contributed to the solution of some problems of living and have created others.
4. Show how certain social prejudices have retarded the application of science discoveries in problems of everyday living.
5. Expand the interests of students.

[2] TAYLOR, HEIL, AND SCHAEFER, J. CHEM. EDUC., 18, 10–14 (1941).

[3] "Science in general education," The Progressive Education Association, D. Appleton-Century Company, New York City, 1938, p. 23.

Each one of these objectives needs further investigation. It is desirable if not essential that each of these objectives be defined operationally, that is, in terms of what the students should be able to do as a result of having taken such courses. In the process, questions such as the following arise:

What is critical thinking? What is the scientific method? What is the scientific attitude? What is the function of logic in the scientific method? How much formal logic is desirable? What facts, principles, concepts of science are desirable for general education? What historical materials should be selected? What problems that have been created by science should be selected?

The problem of objectives may be investigated in several ways. One method is, of course, the questionnaire method, to discover what is the prevailing opinion of teachers. Another method would be to analyze those courses which have been organized for purposes of general education in order to discover the elements which might be characteristic of general education. Another procedure might be the analysis of examinations given at the completion of such courses, not only to discover what elements of general education are tested for, but also the extent to which there is consistency between the stated objectives and the outcomes actually called for in the examination.

In all these methods of investigation, however, the implicit assumption is that the present opinions and practices are essentially satisfactory and we have only to improve upon them. We need other methods that will permit us to get outside this closed circle. One is to start from the definition of general education and deduce its logical implications. Another is to investigate the needs of our citizens, by taking inventories of their interests, activities, situations, and the types of problems which they are likely to meet in actual life. The latter method has already been used by the Cooperative Study in General Education.[4]

A third problem is that of curriculum construction—the type and content of courses that may be organized for this purpose. The content will depend upon the objectives, the type of course, the length of the course, and the type of student population. Questions of this type will arise: How much emphasis should be placed on theory, on facts, on definitions, on symbolism and nomenclature? How much emphasis should be placed on skills such as balancing equations and solving quantitative problems? Is laboratory work desirable? If so, what kind of laboratory work? Is development of manipulative skills important?

At present, instruction for general education is cared for in three ways.

1. The traditional chemistry course which is designed primarily for the specialist.
2. Special chemistry courses which have been specifically designed for the non-specialist.
3. Survey courses which consist of material taken from chemistry and other sciences.

In each of these types special problems arise. In the traditional type, the attention is largely centered on the problem of caring for the specialist and the non-specialist in the same course. In the survey course the problem is one of integration with the other sciences.

Another problem is that of providing instructional material for courses in general education. Those who have attempted to give such courses are painfully aware of the lack not only of basic texts but of collateral readings. The texts on the whole have been slight modifications on the traditional type. Wherever the texts have departed considerably from tradition, they have tended to become superficial. The collateral reading available is even less satisfactory. The available material is either too technical and incomprehensible or too "popular." There is a real need for material written specifically for this purpose. We are laboring under the misconception that courses for general education may be devised by simply omitting the difficult material from the traditional courses. We have not yet grasped the idea that the functions of the two types of courses are different, that the course for general education can be made just as intensive and difficult as the traditional courses, with its emphasis, however, on different aspects of chemistry.

Another problem is the development of tests which will measure the outcomes of instruction. It is well recognized that at present there are no completely satisfactory tests to measure such objectives as critical thinking or the scientific attitude. In this area we need the aid of specialists who are experimenting in the construction of such tests. Eventually, however, it would be desirable to help the teachers themselves to construct these tests.

Finally, a major problem is the matter of personnel. There are two serious difficulties. One is the difficulty of finding competent chemists who at the same time have a sufficiently broad background and sufficiently broad interests to understand the problems and devise methods of solving them. For it goes without saying that the courses would not be better than the teachers who teach them. A second difficulty is in keeping these people, once they have been found. For if the present emphasis on "pure research" for promotion is continued, few people of ability would continue to devote their energies to a purpose for which no recognition in terms of advancement is made, however strongly they might feel that such work is important to society.

It is interesting that, in general, teachers feel that lack of recognition for teaching ability is one important factor for the neglect of this function. In the study referred to above is the question, "Do you consider that the emphasis placed on 'pure research' as a basis for advancement of the instructional staff has retarded the development of a real concern about, and research upon teaching problems related to general introductory

[4] HEIL, "Determining objectives of science instruction for general education," *The Educational Record*, 1942, 94–105.

courses in chemistry?" Seventy per cent replied *yes*, 17 per cent replied *no*, while 14 per cent were uncertain.

The author is aware that the foregoing analysis of the problem is barely a beginning. There are many problems that have not been mentioned, and doubtless others that the author has not recognized. Merely to find and list all the problems would require the careful consideration of a large number of individual teachers. It might be desirable that some group assume the responsibility for defining the problems, planning investigations, and interpreting the results. For the solution of the entire problem would involve not only the solution of individual problems but the integration of the results of the separate investigations. No group is better fitted for this work than the Division of Chemical Education.

The Sequence of Topics in General Chemistry[1]

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ALTHOUGH there is more or less unanimity of opinion regarding the topics to be covered in a general chemistry course, the sequence of the topics is a problem which requires some thought before a definite plan can be formulated. There are many phases of teaching which must be considered before this can be done. The following are some of the factors which should have a bearing upon such a decision:

1. What is the objective of the course in general chemistry in a particular college? If the purpose is to prepare the student for the next course in chemistry, as qualitative analysis, then the topics and their sequence should be so presented that the fundamental principles are included and developed along the lines of a classical course, stressing ionic equilibria.

2. If the course is to be a complete one, not particularly preparing for higher courses, but rather a well rounded basic course which might be the only chemistry course a student will take in his college work, it should present the fundamental principles and their applications, stressing the chemistry of everyday life and industry.

3. Another consideration which should influence the choice and sequence of topics is the previous preparation of the student. If the course is based upon a high-school chemistry course, with perhaps a course in physics and one in biology, the selection and sequence of topics would naturally be quite different, since a certain amount of fundamental and factual information could be taken for granted. Here again one must bear in mind whether the course is to be a preparatory course for further chemistry, or a "dead end" course.

4. There is still another consideration. The course may be designed to meet the requirements of two groups of students: those who intend to go on in chemistry, and those who do not (the arts and social science students). In such a case, depending upon previous training of the students, the choice and sequence of topics must be such that the course will provide basic principles and their applications, and sufficient theory to satisfy the "chemical major" and not too much to discourage the arts student.

The following is suggested for a basic course for students with no previous chemical training:

(*1*) *A course for students who have had no high-school preparation in chemistry.*

1. What is chemistry? How theories and laws are evolved.
2. Chemical and physical changes; elements; compounds and mixtures. Atomic-molecular hypothesis.
3. Oxygen and hydrogen, followed by the study of gases.
4. Water. Kinetic-molecular hypothesis, vapor pressure and hydrates.
5. Molecular and atomic weights. Equations.
6. Hydrogen chloride and sodium hydroxide.
7. Chlorine, sulfur, and their simple compounds.
8. Valence and periodic law.
9. Solutions.
10. Radium and atomic structures.
11. Atmosphere and the inert gases.
12. Carbon and the oxides of carbon.
13. Ionization.
14. The halogens. Oxidation-reduction.
15. Oxides and acids of sulfur.
16. Nitrogen and phosphorus.
17. Metals and metallurgy.
18. The metals may be taken up in any order, and somewhere in this section electrochemistry should be introduced.
19. Organic chemistry, food and nutrition.

Colloids and the study of the solid state may be introduced if found desirable.

Oxygen and hydrogen are introduced before the study of gases so that at least one gas is studied in detail before the general consideration of gases is taken up.

Water naturally follows hydrogen and oxygen and paves the way for such concepts as vapor pressure, boiling and freezing points, hydrates, etc.

Chlorine and sulfur are introduced before valence and the periodic law are considered. This is also a good time to review equations and formulas.

Just how much will be considered under the topic of solutions must be decided in each individual case. One might include supersaturation, immiscible solvents, mixed solvents, osmosis, Raoult's law, fractional distillation, eutectic mixtures, molecular weights of solutes, and constant boiling mixtures, depending upon the time available.

[1] Presented at the Round Table on the Problem of Teaching Chemistry, sponsored by the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

In defense of this sequence, I might say that the student should be presented with a logical development of the subject material and should be impressed with the fact that chemistry is a growing science, involving experimentation. An historical development of the subject accomplishes this end. Of course a strictly historical treatment of the subject cannot be presented in the time allotted. But certain sections can be taken up in historical order, such as the atomic theory, which can be developed in the following sequence:

Atomic molecular hypothesis
Molecular and atomic weights
Periodic law
Radioactivity
Atomic structure

This is a logical development and the historical one. It leads very smoothly into the solid state, to solutions of electrolytes, and oxidation-reduction. While hydrogen, oxygen, water, sulfur, and carbon can be studied before ionization is considered, sulfur dioxide and sulfuric acid cannot.

One should not have any difficulty in introducing the theoretical aspects of chemistry, for theory can be made interesting and can be motivated by practical applications in everyday life, both in recitation and in the laboratory work.

The following selection and sequence of topics is suggested for students who have had high-school preparation in chemistry, with or without physics and biology.

(2) *A course for students who have had high-school preparation in chemistry, with or without physics or biology.*

1. A review of the atomic hypothesis and types of chemical changes.
2. Study of the behavior of gases, the gas laws, and their explanation on the basis of the kinetic-molecular theory.
3. Determination of atomic weights of the elements and molecular weights of gaseous compounds.
4. Energy and chemical change, which then leads to chemical equilibrium.
5. Despite the possible criticism that too much theory is being introduced before some factual chemistry is offered, nevertheless it seems logical to propose: The periodic law and valence, supported by a study of radioactivity and its logical outcome, atomic structures.
6. Hydrogen and oxygen, followed by water.
7. A discussion of the solid state, solutions and their properties.
8. We are now ready for: Ionization and the newer concepts of acids and bases.
9. The halogens and their compounds, followed by oxidation-reduction.
10. The remaining non-metallic elements and the atmosphere. (Carbon and silicon to be included.)
11. Colloids may be introduced at this stage.
12. A general discussion of metals and metallurgy.
13. The metals may then be considered in the light of the Periodic Table, or as special groups. Electrochemistry may be introduced about the time that aluminum or lead is taken up, including E.M.F. measurements and types of cells. Particular metals may be stressed, depending upon the regional requirements (location of the college in mining sections or industrial areas).
14. Organic chemistry, including food and nutrition.

It is my belief, supported by experience with students having previous chemistry in high school, that the above sequence can be carried out with satisfaction and excellent results. However, to avoid the large dose of theory at the very beginning (although I do not find it a serious obstacle), it is possible to introduce the study of hydrogen and oxygen after the section on gases. But the treatment would of necessity be elementary, particularly concerning their preparation, unless one assumes previous knowledge of such caliber as would warrant the use of the concepts of valence, ions and atomic structures, and energy changes. Some objection may be raised to deferring the study of the metals until after the non-metals have been taken up. Naturally some of the metals are introduced during the discussion of the non-metals, but a well-rounded study of metals is hardly possible until after a general discussion of metallurgy, which must follow the study of hydrogen and of carbon and its oxides.

Another question which may arise is the place of atomic structures and the periodic law. It is my belief that they can and should be introduced early in the course so that use can be made of them as often as possible. This is particularly true when the student has become acquainted with them in a previous course.

Finally the place of organic chemistry in the sequence may be considered. Some authors have introduced the topics of foods and synthetic organic compounds before the study of the metals, perhaps as a breathing spell, believing that this phase of chemistry will prove more fascinating and therefore aid in sustaining interest. This, I believe, is unnecessary, for the study of the metals can be made just as interesting. Besides, the study of organic compounds, particularly those dealing with our health and welfare, might well come after the study of all of the elements and the fundamental principles of chemistry, since all are involved in the process of digestion.

If this course is to be a basic course for all students, whether they go on in chemistry or not, we need not go into great detail in the study of the laws and principles, but dwell more upon their applications in a broad way. The details and justifications for our concepts, and the derivations of the laws may be taken up in the advanced courses.

In the teaching of science, according to Franklin T. Jones, a concerted "effort should be made to figure out what should be taught first" and then lead up "to the very interesting things which we learned last," instead of teaching "first the last things we learned."

The Varied Objectives in Service Courses in General Chemistry[1]

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SOME time ago a set of objectives was compiled[2] which was approved by a representative group of college teachers of chemistry. This approval was probably given in the hope that such objectives, when achieved, would lead to successful work on the part of students in subsequent courses.

Such an assumption, that success in one course is indicated by a good record in a subsequent one, is erroneous in at least two particulars. It overlooks the fact that probably more than fifty per cent of these students in service courses will never take any more chemistry, and second, it assumes the doubtful inference that the greatest general good for this group of students comes from remembering and understanding the technical intricacies of general chemistry. It is with this second assumption that the professional schools take issue.

It is a reasonable estimate that fifty per cent of the colleges in which service courses in chemistry are offered make that offering in segregated groups. When staff members of the professional schools are asked to state the advantages of such segregation the answer is commonly made that by this plan chemistry is made to apply to the student's field of interest. Selection of that which applies to a particular field of interest in effect modifies the objectives of a course, both as to subject matter and extent of emphasis. This same practical modification of the aims of general chemistry for pre-professional groups is also implied in many of the textbooks offered for pre-nursing, premedical, and home economics students. Professional schools are really quite serious in their endeavor to have the chemistry taught their students contribute to professional success rather than to high attainment in pure chemistry.

There are two current methods of recognizing these varied objectives sought by professional leaders. The first is that of segregation, thereby providing a group for each different interest. This plan may be operated so that instruction is organized in the department of chemistry or the course may be removed to the professional school's curriculum. On the other hand, a sizable proportion of the colleges and universities try to serve these groups by having them all together with no administrative recognition of the different uses to which they will put their chemistry. This last plan would probably have the approval of a majority of teachers of college chemistry. Their argument would, no doubt, agree with two statements made by men in professional schools whose students were being serviced by such a general course in chemistry. One said, "The principles of chemistry do not vary with professional interest," and the other, "Why is application important in first-year chemistry?"

There is no doubt that trying to meet the problem by what might be called "the composite grouping" has its attractions both to the administrator and the supervising teacher. For the first, establishing fewer units to be instructed decreases the cost of instruction in salary, housing, and equipment cost. By emphasizing principles of chemistry, class groups, ten or twenty or more, can be regimented into a lock-step program of class and laboratory assignments, easy to direct by a division overseer. But such a plan leaves entirely to chance any attention to the chemistry that may pertain to the student's field of interest.

Up to this point one very important party has not been explicitly considered—the student. The objectives of the chemistry teacher have been noted and the professional school's dissatisfaction with the service rendered the student by his school. But the person most concerned has not been heard from. He does have a say, however, before the year's records are filed. His indifference in class and lecture room, his cookbook laboratory performances, and his mediocre attainment in terms of grades are, in all probability, his protests against a system of instruction which gives him no share in its selection and organization.

After all, what difference does it make, anyway? What is the difference between coöperative participation and perfunctory compliance on the part of a student in his school work? When he shares in choosing his desired objectives and helps plan for their accomplishment there will be a sense of responsibility on his part and a consequent greater industry directed toward the achievement of the ends sought. Then, too, learning is a dynamic process of relating the *desired* new and unfamiliar to the *experienced* old. The principles of chemistry, or any other science, are merely the important generalizations. Generalizations are arrived at from particulars. Popular belief notwithstanding, applications, *i. e.*, particulars, precede principles in the learning process. Principles which are understood involve applications, either in their genesis or in their environmental meaning. Thus is answered the question, "Why applications in first-year chemistry?" Unless there are applications it is meaningless. A most certain index of one's knowledge of anything is the extent to which he uses it in his daily activities. Thus

[1] Presented at the Round Table on the Problem of Teaching Chemistry, sponsored by the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

[2] SMITH, "Accepted objectives in teaching general college chemistry," J. CHEM. EDUC., 12, 180–3 (1933).

the classroom teacher soon discovers that, basically, the staff of the professional school, in asking for "application within the field of interest," is requesting that which the alert teacher desires. Successful teaching requires *desire for that taught* on the part of the student and the incorporation of the new into his experience. This is achieved by application within the field of interest.

The problem then is this: Given seven or eight groups, such as premedical, predental, pre-nursing, technicians, pharmacists, and engineers, with as many "fields of interest"; can these students attain a working understanding of some of the essential principles of chemistry, with especial reference to their particular fields of interest—without segregation?

In those institutions where segregation upon the basis of professional interest is practiced, have the results justified the added administrative and financial burden? From the standpoint of the success of a course, is not "ability grouping" more useful than professional grouping? Would not success in securing application of the principles of chemistry in the field of professional interest necessitate teachers who are prepared both in chemistry and in the various professions?

The writer knows of an introductory course in bacteriology in which all groups are together for lectures but the laboratory groups are divided according to professional interests. Would such a plan have value in chemistry?

Another suggestion is that the course be offered with its sole purpose that of providing chemistry's contribution to a general education. Such a plan, it is claimed, would achieve the application of chemical principles within the experience of its students and thus attain motivation of student interest and background for later professional growth.

Whatever the solution may be, most of our teachers of general chemistry in institutions of any size are aware of the teaching problems presented by these service courses in chemistry. When a teacher discovers that 95 per cent of his students are not interested in chemistry for its own sake, but for what chemistry can do for his profession, he begins to understand the indifference of many of his students to the more technical phases of chemistry.

The Importance of Laboratory Work in General Chemistry at the College Level[1]

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THE purpose of this paper will be to review some of the critical teaching problems and controversial issues resulting from past practices in general chemistry laboratory work, to present some of the results of the author's recent questionnaire, and finally to indicate some of the problems of the immediate future.

Austin M. Patterson[2] in a recent article has said:

> "The urgent demand for chemists, laboratory technicians, physicists, engineers, supervisors, and physicians can be presented. There may be dislocations in some of these callings after the war is over, but it seems probable that we are headed toward a more technological type of civilization. This country will need larger numbers of technically educated men and women on various levels if it is to hold its own with strong competing nations, and their training must be more thorough than much of it has been in the past."

It is therefore appropriate at this time to re-examine the general chemistry laboratory program (as well as the laboratory work in more advanced courses in chemistry) with respect to objectives, methods, course content, methods of appraising achievement, etc., particularly as these subjects relate to our war effort and the technological society referred to above.

[1] Presented at the Round Table on the Problem of Teaching Chemistry, sponsored by the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

[2] PATTERSON, "Chemistry teachers and the war," J. CHEM. EDUC., 19, 166 (1942).

OBJECTIVES OF GENERAL CHEMISTRY LABORATORY WORK

Leonard F. Sheerar presented a paper before the regional meeting of the Division of Chemical Education at Omaha on "Suggested Objectives of Laboratory Work in the First Course of General Chemistry at College Level." A selected list of objectives in questionnaire form was sent out to 299 representative colleges and universities. Ninety-four replies were received from 94 institutions in 38 states.

Assuming that a 66 per cent approval indicated the acceptance of the proposed objective, the results of this questionnaire were summarized as follows[3]:

Chemistry laboratory instruction should:

(*a*) develop the ability to make observations, interpret and draw conclusions from observed facts,
(*b*) develop the ability to use simple scientific instruments and manipulate apparatus,
(*c*) develop the ability to keep a record and write a satisfactory report,
(*d*) develop the attitude of drawing conclusions only from observable or accepted data,
(*e*) develop the habits of accuracy, honesty, self-reliance, cleanliness, and orderliness in the laboratory,
(*f*) satisfy the students' curiosity and provide experience to develop latent interests,
(*g*) provide opportunity for instruction.

[3] "Methods of laboratory instruction in beginning college chemistry," unpublished monograph by J. Austin Burrows, Oklahoma Agricultural and Mechanical College.

At the Conference on Examinations and Tests held at the University of Chicago during the week of July 21, 1941, it was tentatively decided to introduce a new section on Laboratory Training into the Coöperative Chemistry Tests for the year 1942.

A committee, made up of Ralph K. Strong, B. Clifford Hendricks, and the author, was appointed to study the possibilities of this test.

Without the benefit of Dr. Sheerar's results our committee proposed a list of laboratory "objectives" as well as a list of laboratory "outcomes" which we felt should be common to all laboratory courses in general chemistry. Copies of these "objectives and outcomes" are available to those interested.

Suffice it to say that these two sets of objectives, independently arrived at, emphasize essentially the same points. As was to be expected, the breakdowns of some of these objectives differ somewhat in detail.

Recently the author sent out a questionnaire to some 175 universities and colleges requesting, along with other information, a rating of some proposed objectives in general chemistry laboratory work. One hundred forty of these questionnaires from 140 institutions in 46 states of the Union were returned.

Without going into an analysis of the results of that part of the questionnaire dealing with laboratory objectives it is significant that the results substantially agree with the above list.

For the time being we may conclude that there is fairly good agreement among college teachers on the important objectives common to all general chemistry laboratory courses. However, these should not be considered as final but rather as a suggested guide for the future. The author is opposed to the philosophy which attempts to standardize our educational procedures, because such a philosophy tends to preserve the status quo and to discourage free research on educational problems. In fact the changes which are now going on in our educational institutions as the result of the war effort may force us to reconsider and reappraise some of these objectives.

METHODS OF LABORATORY INSTRUCTION

The controversy over the merits of the *individual laboratory* versus the *demonstration laboratory* still goes on, with the arguments on both sides still inconclusive. The persistence of the rebuttal on this problem is illustrated by the title of a recent paper by R. L. Cooke, namely, "Demonstration versus Laboratory *Once Again*."[4]

The literature records some fifty references, covering a period of over thirty years, on experimental studies relating to the individual versus the demonstration laboratory. Of these, 45 applied to high-school classes and only five to college classes. Their distribution is as follows: chemistry, 23; physics, 12; general science, 6; biology and zoölogy, 6; botany, 2; and agriculture, 1.

[4] "Demonstration versus laboratory once again," J. CHEM. EDUC., 15, 592 (1938).

The literature also records that 7 investigations of this problem were conducted by means of questionnaires. Thirteen reviews of the findings of previous investigators and 14 papers, expressing the opinions of the authors on this controversy, are also recorded.[5]

The literature reports the work of but two, R. E. Horton[6] and E. O. Smith and his staff, who attempted to measure the outcomes, achievements, and effectiveness of the various laboratory methods by *actual performance tests*. All others used paper-and-pencil tests which in all probability do not measure motor skills, manipulative ability, laboratory technic, and the tangible acquaintance with materials.

Since the investigations of E. O. Smith and his staff seem to the author to be unusually significant, well planned, and particularly relevant to this paper, a brief summary of the conclusions of their investigation will be given.

The details of this investigation, which covered a period of two years, have been presented at different times before regional meetings of the Division of Chemical Education. This entire investigation is carefully reviewed in Burrows' monograph. The final conclusions of this two-year investigation were as follows:

1. The customary method of measuring achievement in elementary chemistry by paper-and-pencil tests measures chiefly the outcome of but one of the major objectives of laboratory work; *viz.*, the acquisition of information.
2. Such paper-and-pencil measures of achievement in chemistry fail to show any consistent or marked advantage for any of the three methods of laboratory procedure studied; *viz.*, the individual, the lecture-demonstration, and the lecture method.
3. At the conclusion of a laboratory course in beginning chemistry those pupils who have had individual instruction do consistently better than those who have seen the experiments performed for them in class or those who have heard the instructor explain the experiments in lecture, when these pupils are measured by a laboratory performance examination.
4. This difference in ability in favor of those who have had one semester of individual laboratory instruction over those who have had the other methods of instruction is not entirely erased at the end of the second semester during which all the pupils have had individual instruction.
5. Since the difference is slight it would appear that one semester of laboratory instruction by demonstration followed by a second semester of individual laboratory instruction accomplishes the same results as two semesters of individual laboratory instruction.
6. It seems probable that the best plan of laboratory procedure is to present some of the experiments, particularly during the first semester, by demonstration. The experiments involving the more complex apparatus, those in which it is the most difficult to obtain the correct results, and those which may have an element of danger involved, are believed to yield the best results to the classes as a whole by the lecture-demonstration method.
7. Contrary to the conclusions of many of the previous investigators the individual method of laboratory instruction is superior, particularly for the superior student, while the lecture-demon-

[5] Symposium on The Lecture Demonstration Method versus Individual Laboratory Work conducted by the Division of Chemical Education at the 89th meeting of the A. C. S., New York City, April 25, 1935.

[6] HORTON, "Does laboratory work belong?" J. CHEM. EDUC., 5, 1432–43 (1928); "Improvement of scientific ability through the use of the individual laboratory exercise in chemistry," *ibid.*, 6, 1130–5 (1929).

stration method may be somewhat better for students at the lower intelligence levels.

8. Further study is necessary to obtain better methods or devices to measure the student's attainment of the generally accepted aims and objectives of laboratory work.

After reviewing the literature, Knox[7] concludes,

"It is evident that the experimental data we possess point definitely to the superiority of the demonstration method so far as those outcomes that may be measured by the ordinary written tests are concerned. The studies referred to do not furnish us with a satisfactory solution of our problem. *A measuring instrument must be devised for determining the educational product unobtainable without the laboratory method.* Indeed, we are not certain what procedure should constitute either the laboratory method or the demonstration method. I seriously doubt the wisdom of standardizing to any great extent either method. Perhaps laboratory work should not be required of all pupils. . . . I am convinced that the abandonment of the laboratory method at the present time would mean a degeneration of science teaching in the secondary school."

It is obvious that much additional research must be carried out by our colleges and universities before a rational answer to this question can be obtained. Universities with large enrolments in their general chemistry classes should be encouraged to study this problem in order to obtain statistically reliable results. It seems reasonable to deduce from the literature that the demonstration method might well be used with those vocational groups in the general chemistry class which normally will not practice or need in their chosen profession the particular skills characteristic of the general chemistry laboratory. In fact Arenson[8] recommends the demonstration laboratory for freshman engineers in chemistry and comments,

"Certainly those students who are going on with chemistry need the experience of glass bending, etc., preliminary to their courses in organic and physical chemistry. But why do these non-chemical engineering freshmen need to burn their fingers making glass bends?"

Hunt[9] calls attention to the economic aspects of individual laboratory work with respect to laboratory space, apparatus, and chemicals. The author has attempted to analyze this question further as it relates to all of the colleges of the United States.

The total number of students enrolled in general college chemistry in the United States in 1941 is estimated conservatively at 200,000.

The estimated cost of chemicals per student per year is \$1.50; therefore the total cost of chemicals is	\$ 300,000
The estimated annual depreciation of student apparatus including breakage, non-returnables, lock and key, and the prorated share of storeroom help is \$5 per student, or a total of	\$1,000,000
Total annual depreciation of chemicals and supplies	\$1,300,000
The estimated value of the locker equipment per student is \$10, or a total capital investment in locker equipment of	\$2,000,000
The accessory equipment used in common by the class, such as trip balances, analytical balances, Kipp generators, barometers, etc., prorated at \$3 per student represents a total capital investment of	\$ 600,000
Total capital investment in the more permanent laboratory equipment	\$2,600,000

The above estimates are conservative and do not include overhead for laboratory instruction, supervision, heating, lighting, and janitor service and such desk services as gas, electricity, water, steam, air, and repairs. They also do not include the high-school group.

One large university submitted an overall cost (including cost to student and to college) of \$71.50 per student per year for individual laboratory work. Another estimated \$65 on the same basis.

If we assume an average overall cost per student per year of \$50 (based on a low of \$25 and a high of \$75) the total cost per year of giving individual laboratory work in general college chemistry in the United States is \$10,000,000. In this connection it should be pointed out that the chemistry departments of but few colleges know their costs in giving individual laboratory work, so that the above estimates are based on rather meager information.[10]

The "all out" war effort, priorities, the scarcity and increase in the cost of chemicals and apparatus, competing defense courses, the possible decrease in departmental budgets, the drafting of teaching personnel, etc., will all contribute toward forcing our departments of chemistry to examine critically their methods of laboratory instruction.

METHODS OF TESTING FOR LABORATORY ACHIEVEMENT IN GENERAL COLLEGE CHEMISTRY

The results of the author's questionnaire gave ample proof that teachers of general college chemistry are interested in new and improved testing devices, particularly as these relate to laboratory achievement.

The common practice of rating laboratory achievement in general chemistry is to obtain a composite score made up of the scores on the student's notebook, oral and written quizzes, supplemented by a general subjective appraisal based on firsthand observations of the student's performance. Teachers vary consider-

[7] KNOX, "The demonstration method of teaching chemistry," J. CHEM. EDUC., **13**, 166 (1936).

[8] ARENSON, "Demonstrations vs. chemistry laboratory for freshman engineers," *ibid.*, **18**, 241 (1941).

[9] HUNT, "Demonstrations as a substitute for laboratory practice in general chemistry," *ibid.*, **12**, 73 (1935).

[10] *Note:* The above estimates are based on the following data: The total enrolment in the colleges of arts and sciences, junior colleges, professional schools, and extension services of college grade for 1941 is 1,600,000. (Data obtained from Dr. Walton C. John, Department of Education, Washington, D. C.) The per cent of the total enrolment taking general college chemistry each year is estimated at 12 to 13 per cent. This figure is based on the average of some 20 representative schools (liberal arts, universities, and engineering schools; the variation ranged from 11 to 25 per cent). Also, the above figure of \$300,000 for chemicals is in line with figures supplied by a large chemical manufacturer of reagent chemicals, who estimates that high schools and colleges use from \$500,000 to \$750,000 in reagent chemicals each year; industrial laboratories, \$2,000,000 to \$2,250,000; and research laboratories approximately \$250,000.

ably in the emphasis they place on each of these separate scores and the weight of the composite score on the general chemistry grade.

The following table presents the results of the questionnaire on this point calculated for the average college practice in rating laboratory work.

TABLE 1

AVERAGE COLLEGE PRACTICE IN RATING LABORATORY WORK

		Factors Involved in Laboratory Grade				
Type of College	% Wt. Lab. Grade on General Grade	Notebook, %	Observation of Performance, %	Oral Quizzes, %	Written Quizzes, %	Miscellaneous, %
Liberal arts	29	32	29	12	23	4
University	26	38	19	6	34	3
Science, Engineering, Agriculture, and Technical	30	30	30	18	22	0

Very little progress has been made in developing adequate devices for measuring the achievement of the accepted objectives of laboratory work in general chemistry, other than the acquisition of knowledge. The paper-and-pencil measures of chemistry laboratory achievement that have thus far been devised fail to show any consistent or marked differences among the several methods of laboratory instruction.

Performance tests, such as those reported by E. O. Smith and his staff, have produced encouraging results in measuring some of these laboratory objectives. Other studies are needed, particularly on the part of our larger colleges and universities, in order to obtain statistically significant results so important in investigations of this kind.

The principal objections registered against performance tests include: the difficulty of administering them, the addition to the teacher load and departmental budget, and the disruption of the departmental routine. Also some colleges, that have tried them, have had difficulty in getting agreement of the subjective opinions of the judges and in addition feel that the student is not being rated under normal laboratory conditions. Notwithstanding, the author feels confident that more pioneering work in this area will remove many of these objections and that practical performance tests will become a part of our testing program in the not too distant future.

For the past five years the chemistry department of Antioch College has been making subjective appraisals of laboratory performance on each freshman chemistry student at each laboratory period. The student is rated on manual skill and manipulative technic, efficiency in using laboratory time, understanding of his laboratory problem, self-reliance and resourcefulness, and care and orderliness in experimentation. These values on his laboratory work are graphically rated on a line from low to high. At the end of each eight laboratory periods a composite score of each of these values is made and transferred to his permanent record card. A total of thirty-two ratings on each of these values is made during the year. Granting that the individual subjective ratings of the student's behavior with respect to these values may be inaccurate, the composite ratings will approach the student's average behavior and become increasingly reliable. We have found these ratings of the students' laboratory performance of great importance to our personnel department in placing our students on coöperative jobs. Our industrial employers want students who can use their hands as well as their heads.

This year's Coöperative Chemistry Test will include a section on Laboratory Training. As a paper-and-pencil test it probably will not measure laboratory technic, manipulative ability, etc., but the test committee and the teacher critics feel that it measures something not covered by the rest of the examination. It is experimental, but the author believes it is a move in the right direction.

RESULTS OF OTHER PARTS OF THE QUESTIONNAIRE

The results of other parts of the author's questionnaire, calculated for the average college, are tabulated in the tables which follow. For purposes of study the questionnaires were divided into three groups, namely liberal arts colleges, universities, and science, engineering, agricultural, and mechanical colleges. Questionnaires were received from 78 liberal arts colleges, 48 universities, and 14 science, engineering, agricultural, and mechanical colleges.

In many cases the deviations from these averages were considerable, but it was felt that average results would be more significant for the purposes of this round table discussion.

Table 2 presents the results of the questionnaire relating to the percentage of the students in general college chemistry who have had previous high-school chemistry. It also includes the percentage distribution of students based on vocational aims.

Table 3 presents the results of the questionnaire relating to the segregation of general chemistry students into courses based on previous experience or vocational aims. It also shows whether students with previous chemistry perform the same or different experiments

TABLE 2

PREVIOUS TRAINING AND VOCATIONAL DISTRIBUTION OF STUDENTS IN GENERAL COLLEGE CHEMISTRY FOR THE AVERAGE COLLEGE

		Vocational Aims					
Type of College	Previous Chemistry, %	Chemistry, %	Other Sciences, %	Engineering, %	Premedical, %	Home Economics, %	Liberal Arts, %	Miscellaneous, %
Liberal arts	56	13	8	7	18	7	38	9
University	69	14	12	31	13	8	8	14
Science, Engineering, Agriculture, and Technical	64	11	7	28	10	17	12	15

TABLE 3

SEGREGATION OF STUDENTS IN GENERAL COLLEGE CHEMISTRY FOR THE AVERAGE COLLEGE IN CLASS AND LABORATORY. INCLUSION OF QUALITATIVE ANALYSIS

Type of College	Segregation in Courses Based on Previous Experience or Vocational Interest: One Course for All Students, %	Based on Previous Chemistry, %	Based on Vocational Interest, %	Previous (or no) Chemistry Same Lab. Experiments Yes, %	No, %	Some Expts. Common to Both, %	General Chemistry Includes Qualitative Analysis: Yes, %	No, %	No. of Weeks
Liberal arts	68	17	15	58	8	34	59	41	13
University	39	20	41	57	2	41	77	23	13
Science, Engineering, Agriculture, and Technical	23	8	69	77	8	15	62	38	13

TABLE 4

TEACHER-BELIEFS ABOUT "CARRY OVER" OF "OUTCOMES" FROM GENERAL CHEMISTRY LABORATORY EXPERIENCES

Type of College	Scientific Method Yes, %	No, %	Critical Observation Yes, %	No, %	Manual and Manipulative Skill Yes, %	No, %	Self-reliance Yes, %	No, %	Resourcefulness and Ingenuity Yes, %	No, %
Liberal arts	89	11	89	11	88	12	92	8	85	15
University	95	5	96	4	100	0	96	4	91	9
Science, Engineering, Agriculture, and Technical	100	0	83	17	100	0	75	25	80	20

from those with no previous chemistry. The table also shows the percentage of colleges that give qualitative analysis as a part of the general chemistry course.

Table 4 presents the results of the questionnaire relative to teacher-beliefs about "carry over" of the "outcomes" from general chemistry laboratory experiences. These results should not be considered too significant, since the question of "carry over" depends so much on the student and the teacher's ability to generalize and point out to the student the possibilities of this "carry over."

Ninety-five questions from fifty-four schools were received in response to the author's invitation, in the questionnaire, to send in questions on laboratory work for this round table discussion. Not all of these questions were relevant to this paper. The author has attempted to summarize the pertinent questions in the order of their frequency.

1. What will be the effect of the war on laboratory work in general chemistry with respect to content, costs, teacher load, etc? Should special emphasis be placed on certain fields during the war emergency?

2. The general question of quantitative experiments in general chemistry was frequently raised, *i. e.:* Is the emphasis upon quantitative experiments justified in view of the type of apparatus and balances generally furnished? Do such crude experiments promote careless technic in advanced work? What kind of balances should be used? etc.

3. Should qualitative analysis be a part of general chemistry laboratory work? If so, how much? Should it be followed by a more extended course in qualitative analysis? "The problem that bothers many departments is the teaching of general chemistry in class and qualitative analysis in the laboratory, although the general qualitative theory is more difficult than that of general chemistry."

4. In order to appreciate the scope and economic aspects of the chemical education problem in this country, the Division of Chemical Education should undertake to collect and compile information from year to year on:

(*a*) The number of students registered for courses in high-school and general college chemistry;

(*b*) The number of students registered in the more advanced courses in chemistry;

(*c*) An economic study and analysis of the costs of individual laboratory work in general and advanced courses in chemistry;

(*d*) Analysis of the additional teaching load resulting from individual laboratory work.

5. What can we expect in the way of devices or tests to measure laboratory knowledge and performance? Ways of making subjective observations valid? Methods of grading laboratory reports?

6. Segregation in class and laboratory based on previous training versus vocational interests versus qualifying examinations given at the beginning of the course?

7. To what extent should the classroom and laboratory work be correlated and synchronized?

8. What are the minimum requirements in a laboratory course in general chemistry?

9. What is the most efficient length and spacing of laboratory periods?

10. The desirability of the demonstration laboratory for students repeating one or both semesters of general chemistry? What should be done with first semester failures in general chemistry?

11. How can the laboratory work be correlated better with the students' previous experiences? How can we increase student interest in laboratory work?

12. Are we ready for semimicro methods in general chemistry laboratory work?

13. To what extent should students work together on experiments?

14 What form of experiment entries is best for the arts student, for science majors, and for nurses?

15 To what extent should a student prepare in advance for a laboratory experiment?

16. What training should laboratory assistants have who are in direct charge of the laboratory?

Many other questions relating to more specific educational problems were asked. Time and space do not permit their inclusion in this paper but they should be kept on file for future reference.

In terms of modern values, the salary of Galileo at the University of Pisa was fifteen cents a day.

The Perennial Problem of Course Content in a Growing Science[1]

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A DISCUSSION of this sort presumably has as its aim the raising of questions rather than the settlement of problems. The former is easier, at any rate, for most of us are willing to admit the problems, while few of us agree upon a particular solution of any one of them. Nor is this illogical, for teaching is a person to person relationship, and solutions of its problems are therefore many and various.

I realize that I am merely trying to say things which a good many of us have talked over a great many times. It should be made clear at the outset, however, that my teaching experience has been exclusively in the small cultural college, a fact which inevitably controls the angle of view of whatever follows.

As I look back on my own undergraduate work in chemistry, I am not so greatly impressed by improvement in the way we teach nowadays, or by the finer laboratories in which we teach, or by our better textbooks, or by our pondering of objectives, as by the tremendous increase in the mass and bulk of the material to be taught. In the growth of our science in recent years, new knowledge and new theories have seldom *displaced* old. Chemistry is now too mature for that. Knowledge and understanding are continually being added, modifying previous views and enlarging them, and increasing the descriptive information available at an appalling rate.

Those of us who have been teaching for some years have grown more familiar with our subject, and have managed, more or less well, to incorporate new developments into our thinking. As a result, things which used to puzzle us now seem clear and simple, and we tend to get the notion that, presented in our own inimitable way, they must slip without friction into the thought stream of the student. If they had only been first presented to us with such crystalline lucidity! Well, they probably were. Lucidity is a product of experience on the part of the listener as well as of ability on the part of the speaker.

It is good exercise for us to think back to the things that used to seem difficult to us. Present-day students are not more mature than students of our day, or, on the average, more intelligent, or better prepared. Yet we have a much more complicated subject matter to present, and it is our job to see to it that they get a firm grasp of its outline and a clear understanding of its fundamentals.

If we could assume that students would come to college with better and better preparation, we could look forward to a degree of relief as a consequence. But no such assumption can be made. It is not my intention to add a few feeble personal lashes to the already well-castigated effigy of Chemistry in the Secondary Schools. But in our discussions of methodology, and objectives, and examinational panaceas, have we not, perhaps, left out the most significant factor in the present status of secondary-school education—*viz.*, the economic one? With salary levels as they are in most parts of the country, what young man with a normal ambition for the amenities of life and for a reasonably well-supported family, can direct himself enthusiastically into the secondary-school field? How many of us have recently advised an intelligent and personable student that high-school teaching was his proper field? In a country which has been able so splendidly to reward all sorts of amusers and gadgeteers, it certainly requires a double portion of the spirit of sacrifice to induce an able young man to take the vows of secondary-school poverty. Of course, there are many exceptions both of people, and schools, and localities, but, by and large, the condition of secondary-school teaching seems to be less a matter for discussion, than a matter of observation on the economic front. There is no evidence of change for the better in the near future.

The problem is thus one for the college teacher, and, the university man will mutter, for him, too—seeing the kind of student he gets from the colleges. Consideration of it leads one to suspect that the first need is a careful consideration of the content of the courses in the chemistry curriculum, with a view to simplification, emphasis on fundamentals in each course, and a real integration of courses so that the graduate will not only be familiar with developments in all important fields, but will also be confidently grounded in the fundamentals of the science. Many of us have assumed that if basically important items are stressed briefly in Course 1, and then again in Course 2, Course 3, and Course N, this repetition will assure fixation in the student's mind. Senior comprehensive examinations too often show that this is not the case, even with some of our best students. May it not be better to cover less material in each course, but do what is done thoroughly enough so that subsequent repetition is unnecessary?

One of the difficulties with such a program is that it runs counter to the prevailing educational theory which demands a continual enticing interest in each day's presentation. But is a student whose flagging will must be energized by daily shots of this kind of stimulant really interested in chemistry at all? It is trite enough to say that the mastery of any subject involves

[1] Presented at the Round Table on the Problem of Teaching Chemistry, sponsored by the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

a proportion of inescapable drudgery, and that only the person willing to undergo it has the necessary drive for success. But like so many trite sayings it is also a true one. It is not our job to make chemistry factitiously interesting, but to present it well, so that those whose natural bent lies in that direction will catch the interest which the subject inherently holds for them. There is no great fun either for us or for the student in that drill on fundamentals which makes them a permanent mental possession. But, on the other hand, there is no ultimate fun in chemistry for anyone who is uncertain in his approach to common chemical problems, unsure of the common typical reactions, unable to write an equation without the book at hand, and doubtful as to the color of ferric hydroxide. We realize the difficulties of the student who does not automatically know the operations of simple algebra, the handling of logarithms, or even the facts of the multiplication table. We ought to see to it that we do not send him forth in a similar state with regard to the fundamentals of chemistry.

The average modern elementary chemistry textbook is to me a fearful and wonderful spectacle. It is almost always well and clearly written, and logically arranged, but it contains practically everything in chemistry. To its original content of descriptive inorganic chemistry has now been added a sizable chunk of organic chemistry, the outline of physical chemistry, and the principal items of industrial chemistry, while its laboratory manual usually includes the scheme of qualitative analysis, and a number of quantitative procedures. To teach from such a book is fun, and the better students do, unquestionably, understand each item as it arises. When they appear the next year in Course 2, however, their retention is often pitifully small. They are like people who have taken a rapid automobile trip through interesting country. Each feature of the scenery was appreciated at the moment it flashed past, but at the end of the trip the principal residue is a vague feeling of enjoyment.

Decisions as to the proper content of an elementary course are always difficult, and especially so in smaller institutions, where, of necessity, students with different aims must be taught together. Obviously, those things must be included which the student who will take no further courses in chemistry may reasonably be expected to need to know. For this reason the modern tendency to include a sketch of organic chemistry seems thoroughly desirable, although in courses intended specifically for chemistry majors it might well be omitted. For these students the real aim of the course should, it seems to me, be such a grounding in fundamental theories and facts that the resulting knowledge can be relied upon to be there when we wish to build upon it in the more advanced courses. I think most of us will agree that the basis of the course should be an exposition of the facts of atomic structure, rather than of the methods by which they were obtained, and the application of these facts, through the periodic system, to the chemical behavior of elements and compounds. We are fortunate, in chemistry, to have so powerful a coordinating mechanism. In this regard the newer developments have simplified our task rather than complicated it.

There will be no corresponding agreement as to topics which may be omitted. May I suggest the following as a few possible examples:

1. The balancing of oxidation-reduction equations, except in the case of the simplest direct electron-transfer types. If the time ordinarily consumed by this topic were used for drill in the simple equations, valences becoming a matter of instantaneous recollection, sufficient time could easily be saved in qualitative or quantitative courses to do a thorough job with the oxidation-reduction type there. Only extended drill will ever give real facility in writing these equations accurately—drill involving so many different examples that the memorizing of coefficients becomes obviously unprofitable.

2. Complicated examples of chemical equilibria, solubility products, and the like, most of which are fictitious anyway. If the principles are fixed in the mind by many examples of the *simplest* type, the work of advanced courses will again be so relieved that complexities can be adequately dealt with in them.

3. Calculations involving the normality concept. No student who does not proceed beyond the elementary course will ever have need for these. And how pleasant it would be for the instructor in quantitative analysis to be able to present the normality idea as a new procedure for simplifying calculations, rather than as a revival of an old puzzle. He could spend all the time necessary on the subject if he could rely on the student's retained ability to do simple gravimetric proportions as a matter of course.

4. All except brief reference, with no expectation of retention, to such topics as the application of X-rays to the determination of crystal structure, radioactive degradation series, methods of determining molecular weights (except direct applications of Avogadro's law, and perhaps freezing point depression), colloid chemistry, the meaning of electrode potentials, etc.

We need an elementary course which is *elementary*, but *intense*, and which stresses descriptive inorganic chemistry to a greater extent than is now customary. It is more fun to teach theory, and it is not necessary to require the student to develop a memory like a memorandum book. But it may be advisable to restrain ourselves a bit on the theoretical side, and make sure that the student acquires enough information about the appearance and properties of things to be able to think through simple chemical situations intelligently. It would be a pleasure to find a qualitative class that did not have a vague collective idea that potassium iodide ought to be purple.

The analytical courses are, perhaps, the least cluttered of any, though this may be true partly because so much of the apparatus required for the newer quantitative procedures is so outrageously expensive, so specific in its applications, and so subject to depreciation in student hands. In general, the items of theory

considered in these courses are those directly applicable to the laboratory procedures. In this connection it seems to me regrettable that the qualitative course is now so frequently compressed into the elementary. In no field of chemistry is it possible to correlate so closely a substantial body of theory with things actually seen in the laboratory. The course is well worth inclusion in any chemistry curriculum as a separate subject.

Perhaps the most frequent sin we commit in the quantitative course is the assignment of peculiarly intricate problems before the calculations of simple gravimetric and volumetric determinations and standardizations have become automatic. It is rare, in an industrial laboratory, to find a recent college graduate who can make these simple calculations with the ease with which he could make change for a dollar bill. Yet he should be able to do so. Here, again, drill alone can produce the requisite facility, and this facility is of more importance than the ability to solve, with much strain, that peculiar kind of analytical problem in which the analyst is represented as proceeding from New York to Chicago via San Francisco and Alaska, traveling sometimes by ox team and sometimes by canal boat. It should be easily possible to teach all of the significant varieties of quantitative calculations by means of examples which the student can clearly see to represent situations which might actually arise in intelligently conducted analytical work.

The astounding expansion of organic chemistry in recent years needs no comment. But, again, we must be careful to realize that there has been no comparable increase in the rate at which the student can acquire permanently fixed information. Most of us probably have a two-year sequence of organic courses, and most of them are being packed too full. Some reasonable selection of topics for the first course should be made, taking only as many as can be adequately covered, using many examples to illustrate each significant reaction. It may be necessary to exclude items the omission of which will make our hearts bleed, but it is less important to cover the entire field than it is to have a satisfactory nucleus of information and understanding firmly fixed in the student's mind so that he becomes literate in the subject. There are books, and no one needs to be *taught* all he is ever going to know.

For the second course in organic chemistry the present vogue of qualitative organic analysis unquestionably represents a distinct advance. Probably no other scheme is as effective as this for the acquisition, correlation, and use of a large body of information in the organic field. The student's interest is aroused and maintained in a perfectly natural way, and, with good retention of information from the first course, he soon finds himself able to use his knowledge in a very satisfying fashion.

If, now, the fundamental basis of chemical understanding has been laid in the elementary course, the theory of solutions well set forth in the qualitative course, the theory of electrode potentials added in the quantitative course, and certain topics, such as the parachor, taken care of in the organic courses, a reasonably adequate treatment of physical chemistry will have been made possible. This is the course in which we are sinners all. There are so many enticing developments, in so many directions, about which we can hardly restrain ourselves from talking. Yet the fundamentals must first be dealt with, and sufficient time assigned to them, and again we must learn to rely on the developing chemical literacy of the student. The question of the thermodynamic versus the kinetic approach is one which, I suppose, we have all struggled with. I think we need to keep in mind the fact that the rigorous beauty of the thermodynamic method is almost never apparent to the student who has no satisfying kinetic picture of the situation under consideration. For the liberal arts college, at least, where it is usually impossible to give more than one course in physical chemistry, the kinetic approach, with its visualizable mechanisms, is most effective. It should always be possible to include discussion of the fundamental thermodynamic quantities and their simpler relationships, but the thorough treatment of thermodynamics may well be left to the graduate school.

If we can see our way clear to some simplification in individual courses, coupled with a satisfactory integration between them, we shall not, I think, find that we are teaching less, but that we are teaching better, and with more regard to the capabilities reasonably to be expected of the student. We may have to omit a few topics we should like to consider. We may sometimes experience that uncomfortable feeling which comes when a student returning from graduate school tells us gleefully of some great new development he has just heard of, and we, in self-justification, find ourselves saying, "Yes, John R. Doe started that at X University five years ago." The student feels disappointed because he hoped he was the bearer of news, and he feels a bit let down because we knew about it all the time but hadn't told him. And we feel that he should have known we would have kept abreast of an important development like that. Maybe we shall have to put up with a bit of this kind of discomfort, but if we do a better job of teaching, we can afford to.

I do not make these suggestions as one who has put them into practice. With regard to all criticisms here made, I avow myself a most miserable sinner. But I am conscious of a growing feeling that I have been wrong. At all events this matter of actual course content is one at least as worthy of our committee's attention as matters of method.

The protein in soybeans can be used for some of the purposes for which casein is ordinarily used. This should be of interest at the present time when emergency requirements of casein for edible purposes are curtailing other uses of casein.

—LAUCKS

A Diagnostic and Remedial Study of Failures in Freshman Chemistry[1]

F. D. MARTIN *Purdue University, Lafayette, Indiana*

SEVEN years ago F. E. Brown reported his experiences with between fifteen and twenty thousand freshman students under the heading "Why Students Have Difficulties With Freshman Chemistry."[2] Dr. Brown raised several interesting questions concerning the teaching of chemistry. In an attempt to find the answers to some of these problems, a number of investigations have been carried on at Purdue University. The present report presents a summary of the objective data obtained and the administrative actions taken to remedy the deficiencies revealed by these surveys.

In order to understand the significance of these findings, one should know something about the content and organization of the course in which they were obtained. The class is made up of about one thousand or more engineering students, about 80 per cent of whom are not intending to specialize in chemistry. Operating as an integral part of the educational system of the state of Indiana, Purdue University admits to its engineering schools any graduate of an accredited Indiana high school and all out-of-state students who are not in the lower third of their high-school class. Entrance examinations are given in mathematics and English; a psychological test of mental ability is also administered to each student. Students making low grades on these three tests are not excluded from the University but, in case their percentile rankings on the English and psychology examinations are low, they may be assigned to a special non-credit course, covering the essentials of high-school grammar and English composition. The chemistry course includes one lecture, two recitations, and one three-hour laboratory period each week and covers two semesters of sixteen weeks each. In order to insure effective review of each lecture, a set of questions is assigned as home work in preparation for each recitation, and short, written quizzes are given each week. In addition, three long, objective tests are given each semester. At the end of the semester the student is assigned grade points as follows: 6.5 (or *H*) to the exceptionally proficient students, 5 (or *A*) to the other high-ranking students, 4 (or *B*) to students doing well enough to merit a grade above the minimum passing grade, which is 3 (or *P*). Students failing to meet the minimum requirements are given 2 (or *C*) in case the work can be made up by examination, 1 (*D*) for complete failure necessitating the repetition of the work in class. By multiplying the points received in each course by the number of semester hours of credit assigned in that course, adding these products, and dividing by the number of credit hours, a "point index" is obtained which serves as a measure of the student's general scholastic achievement. Thus an average of 5 or better would place the student on the honor roll and an index of 4.5 would be better than average. On the other hand, a student must maintain an average of about 3.6 in order to meet the requirements for graduation in four years from the engineering schools. Also, the local draft board will not grant deferment from active military service to any student whose index falls below 3.5.

The records of freshman engineering students for a period of several years were examined and classified with the purpose of answering the following questions:

1. Is chemistry more difficult, as measured by the number of failures, than other freshman subjects such as mathematics and English?
2. Is the course too difficult for students who have not studied chemistry in high school?
3. Is there any relation between a student's grade in freshman chemistry and his success in subsequent work in the engineering schools?
4. What action should be taken to remedy any undesirable situations revealed by the above surveys?
5. How effective are these remedial measures?

TABLE 1

RELATION BETWEEN FAILURES IN CHEMISTRY AND FAILURES IN OTHER SUBJECTS

	Failed Chemistry, First Trial	*Failed Chemistry, Second Trial*
Failed chemistry, mathematics, and English	32.1%	76.5%
Failed chemistry and mathematics	32.1%	12.8%
Failed chemistry and English	9.7%	6.4%
Failed chemistry and some subject other than mathematics or English	9.2%	4.3%
Failed chemistry only	16.9%	0.0%

From the results listed in Table 1 it is evident that Dr. Brown was right when he said, "those who have trouble with chemistry are generally poor in reading, writing, and arithmetic."[3] Note that nearly three-fourths of the students who failed in chemistry the first time also failed in either mathematics or English or both. In the case of the students who failed to pass chemistry after two successive trials, this proportion rose to over 95 per cent. Moreover, on counting all of the failing grades given the first semester to engineering

[1] Presented at the Round Table on the Problem of Teaching Chemistry, sponsored by the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

[2] *The Hexagon of Alpha Chi Sigma*, 26, 83 (1935).

[3] BROWN, *loc. cit.*

students, it was found that 28.2 per cent were given in mathematics, 19.4 per cent in English, 19.0 per cent in chemistry, and 33.4 per cent in other subjects, such as surveying, shopwork, mechanical drawing, military training, etc. Therefore it cannot be said that the chemistry course caused more failures than any other course; in fact, there were fewer failures in chemistry than in either mathematics or English. Unless we leave out all difficult and precise concepts from our science courses, these courses will continue to be difficult for students who find it hard to read understandingly, to write coherently, and to calculate accurately. On the other hand, college chemistry teachers who "practice chemistry and know the necessity of exactness and precision will not use the term 'chemistry' for a group of generalities and recipes or generalizations incapable of being subjected to scientific test or of being employed in commercial production."[4]

Another teaching problem which never has been satisfactorily solved is the question of what distinction, if any, to make between students who have had chemistry in high school and those who enter without credit in high-school chemistry. After several years' trial of assigning different work to the two groups, Purdue University found this method to be unsatisfactory. There was too great a variability in the quality and quantity of chemical knowledge acquired in the various high-school courses; furthermore, when assignment to the "advanced" section was made compulsory, some students felt that they were being penalized for submitting credits in high-school chemistry by being forced to do harder work in college. The present plan is to assign all students of engineering to the same class regardless of whether they have had high-school chemistry. Students may *elect* to take an advanced course in place of the regular course and are offered the inducement of saving one semester's time in case they succeed in making a grade of *B* or better in this course. While this arrangement is very satisfactory for the superior students, it results in complaints from some of the poor students in the regular section. These objections are that it is unfair to put students with no previous chemistry training in the same class with students who have had chemistry before. Although the elementary course is specifically planned to meet the needs of those who have no previous training in chemistry, statistics over a period of several years indicated that the percentage of failures in the group (Group I) which had not had high-school chemistry was significantly higher than in the group which had taken chemistry in high school (Group II). A partial explanation for this difference was discovered when it was noted that there was a much larger percentage of students with low entrance grades in mathematics in Group I than in Group II. Since the average percentile rank of all students failing chemistry with a grade of *D* had been found to be 33.2 (26.3 in the case of those who failed chemistry twice), it seemed plausible to assume that the higher percentage of failures in Group I might be ascribed to insufficient preparation in mathematics rather than to lack of high-school chemistry. Table 2 presents some data which tend to support this hypothesis.

TABLE 2

COMPARISON OF CHEMISTRY GRADES AND PERCENTILE SCORES ON ENTRANCE TEST IN MATHEMATICS

	Average Percentile Rank on the Mathematics Test			
	First Semester		*Second Semester*	
Chemistry Grade	*Group I No High-School Chemistry*	*Group II High-School Chemistry*	*Group I No High-School Chemistry*	*Group II High-School Chemistry*
H	76%	85%	71%	81%
A	72%	71%	73%	70%
B	61%	56%	68%	62%
P	51%	45%	53%	54%
C	50%	45%	47%	52%
D	35%	31%	45%	46%

It will be noted that in the first semester the pupils who made high grades in chemistry ranked in the upper quartile in the mathematics test, while those who received *D* in chemistry were in the lower third of the class in the mathematics test, regardless of whether they were in Group I or Group II. Second semester mathematics test averages at the different chemistry grade levels tend to be somewhat higher than those in the first semester, owing to the "screening effect" of the first semester, which tends to eliminate those students with low grades in the mathematics test. A random sampling taken of a class in the middle of the semester showed that the difference between the average standing in chemistry of Group I and Group II was larger for students ranking in the lowest third of the class in the mathematics test but became progressively smaller as the percentile rank in mathematics increased. This portion of the investigation emphasizes once more the importance of sound mathematical training for pupils intending to take a course in college chemistry, especially when the course stresses laws, theories, and principles, as applied to the solution of specific problems. While the student without high-school chemistry may need some extra help in the first semester, the data indicate that his grade at the end of this semester and at the end of the second semester will not be significantly different from that of a student who has had high-school chemistry, providing both students have about the same proficiency in mathematics.

Chemistry as a science is not a direct prerequisite to such engineering courses as applied mechanics, electronics, and bridge design, but it is a very necessary introduction to many courses in chemical and metallurgical engineering. Several years ago the large influx of students into the Schools of Chemical and Metallurgical Engineering brought up the question of limiting the enrolment. The author was asked to make a specific recommendation which would tend to restrict enrolment in these schools to students who had demonstrated, in the freshman year, their aptitude for chemistry. A study of that year's senior class showed that 62 out of 64 or 97 per cent of the students who received degrees in chemical or metallurgical engineering had received the equivalent of a grade of *B* or better in chem-

[4] BROWN, *loc. cit.*

istry in the freshman year. It was further shown that, had enrolment in these schools been limited to students who made the equivalent of a grade of *A* or better in freshman chemistry, 21 students who were members of the senior class would have been excluded. Of these 21 men, 9 failed to receive their diplomas in June because of scholastic deficiencies, and ten more were graduated with rather low average grades. Two of the 21 had records which gave them point averages of slightly more than 4.0 (*B*), whereas the average of the students who would not have been excluded by the *A* requirement in freshman chemistry was 4.38.

To determine whether the standards in freshman chemistry were such as to result in the failure of students who might succeed in graduating as civil, electrical, or mechanical engineers, the grades in freshman chemistry of all the students who were registered in the engineering schools at Purdue University in October, 1940, were examined. Only three out of 479 seniors had received a *D* grade in chemistry. Of the seniors who had taken chemistry at Purdue University in the freshman year, 99.4 per cent had passed this course the first time. Table 3 gives the exact figures and also shows the marked difference in the grade point averages and the percentage survival.

TABLE 3

A COMPARISON OF FRESHMAN CHEMISTRY GRADES WITH GRADES AND PER CENT SURVIVAL IN THE ENGINEERING SCHOOLS OF PURDUE UNIVERSITY

		Senior Engineering Students 1940		
First Semester Chemistry Grade	*Freshman Class 1937 No. of Grades*	*No. Surviving, Senior Year*	*% Survival*	*Scholastic Index*
H and *A*	325	261	80.4	4.31
B	275	134	48.7	3.75
P (or *C* removed by examination)	350	81	23.1	3.52
D	159	3	1.9	3.36

To determine whether the 98 per cent of the *D* chemistry students who dropped out of school did so because of their low standing in chemistry or because their grades in other subjects were also unsatisfactory, a check was made of the status and average scholastic index of each engineering student who received a grade of *D* in January, 1939. There were 139 of these students, constituting 14.4 per cent of the class. Table 4 shows the records of this group of students in subsequent work at Purdue University.

TABLE 4

STATUS AS OF JANUARY, 1942, OF 139 ENGINEERING STUDENTS WHO RECEIVED *D* IN CHEMISTRY IN JANUARY, 1939

			Scholastic Index		
	Number	*%*	*High*	*Mean*	*Low*
Left school	124	89.2	3.80	2.28	1.00
Stayed in school:					
1. In engineering	8	5.8	3.38	3.01	2.23
2. Transferred out of engineering	7	5.0	3.73	3.35	2.88

As pointed out in the introduction, a scholastic index of 3.60 is necessary to graduate in eight semesters from Purdue University, so it appears that none of the students who stayed in engineering will be able to graduate with their class this semester. Judging from the low scholastic indexes of those who left school, chemistry was not the only subject with which these students had difficulty; in fact, the average number of subjects which these students failed to pass in the first semester was 3.25. Those who continued in engineering encountered trouble with such subjects as calculus, physics, applied mechanics, machine design, and other subjects demanding clear thinking.

These statistics have been presented to show that the problem of reducing the mortality in chemistry for freshman engineers cannot be solved by lowering standards, unless standards are also lowered in all subsequent science courses and in all engineering courses which involve the application of scientific principles and mathematical operations. It would be useless to give credit to students who are unable to master the essentials of freshman science, English, and mathematics, as this could only result in a large increase in the percentage of failures in the sophomore and junior courses. On the other hand, as Dr. Brown has pointed out, "The (failing) student is satisfied with what he knows, but not with his grade. Few members of the lowest 40 per cent ask to be taught more chemistry. They wish to receive higher grades for knowing less."

To reduce the failures in elementary chemistry for engineers without lowering standards, Purdue University has put into effect several administrative rules which have been quite successful. These rules are as follows:

1. In order to register as a sophomore in the School of Chemical Engineering or the School of Metallurgical Engineering a student must have the equivalent of a *B* (or in case the student has had high-school chemistry, an *A*) average in freshman chemistry. Exceptions are allowed if the student passes a comprehensive examination over the work of the entire year in freshman chemistry.
2. A student withdrawing from the first semester chemistry course or failing to pass the course at the end of the first semester is not allowed to repeat the course unless he has passed the elementary courses in college English and mathematics.
3. Students who have not had chemistry in high school and other students who are deficient in their mathematical preparation, as shown by low grades on the entrance examination in mathematics, are assigned to one additional recitation period in chemistry each week unless their average is *A*.

The effect of Rule 1 is twofold: it not only tends to make students intending to specialize in chemistry devote more time and effort to the work in freshman chemistry, but also eliminates from the upper classes in the Schools of Chemical and Metallurgical Engineering those students who are least likely to profit by the advanced work. In the years following the introduction of this rule no change was made in grading standards, but the per cent of honor grades in the freshman course increased by about one half (from 20 per cent to 30 per cent); the failures in the Schools of Chemical and Metallurgical Engineering decreased from an average of 6.15 per cent to an average of 3.15 per cent, and the grade point average of the seniors in these schools showed an increase. While these improvements cannot

be demonstrated to be a straightforward case of *post hoc, propter hoc*, the fact that from fifteen to twenty per cent of the freshmen intending to take chemical engineering fail to meet the entrance requirement set up in Rule 1 shows that this rule is effective in raising the quality of the students admitted to this school.

Rule 2 has been in effect for two years. Before the adoption of this rule the number of failures in the "repeat section" was usually over fifty per cent. By limiting enrolment in this class to students who have passed both mathematics and English, this high mortality rate has been cut to around 10 per cent. The attitude and morale of the class have been greatly improved, also. With the demand for technically trained men greatly exceeding the available supply, an engineering school such as Purdue University must use every possible means for improving both the quality and the quantity of graduates. The exclusion of the weaker students from chemistry has given the University the opportunity to study the individual deficiencies of each student and to assign remedial work in mathematics and English. The number of students involved runs from seventy to seventy-five. A year ago these students were given a series of vocational and psychological tests by the Personnel Department of the Schools of Engineering in hopes that individual conferences and discussions with the weak students would "activate" them. While the complete results of this testing program are not available for publication at present, the fact that the scholastic index for this group of students was 2.20 the first semester (excluding chemistry) and 2.30 the second semester shows that the testing program in itself was not of any significant benefit to the students concerned.

This year it was possible to assign all the students who had been excluded from chemistry, because of failures in mathematics, to a special non-credit class in mathematics, meeting three times a week. Students who were weak in English had the opportunity to attend special classes in either reading or writing articles or both. About one-third of the eligible students attended these special classes in English and mathematics. It will be of interest to note whether this new program of special help for this group of students will enable any of them to overcome their handicaps and graduate in engineering. Last year not a single one of the senior engineering students who received a degree had failed in both mathematics and chemistry in the freshman year.

Rule 3 has resulted in an improved attitude on the part of the students entering without high-school chemistry and Table 5 shows that the number of failures in the regular classes dropped off quite sharply following the adoption of this rule, without any decrease in the achievement of the students as measured by the percentile rank on the Coöperative Chemistry Test.

TABLE 5

Year	*% C's*	*% D's*	*Percentile Rank, Coöperative Test*
1938–39	11.8	12.5	81.9
1939–40	11.3	12.3	82.0
1940–41 (Operating under Rule 3)	7.0	7.7	82.0

Again, it is difficult to say that this 40 per cent decrease in failures is a simple case of cause and effect. From the administrative standpoint it is more efficient to use the time of the chemistry teachers to teach chemistry to the students capable of profiting by it, and to assign students who need help in mathematics or English to teachers trained in teaching these subjects.

It is possible that hypothyroidism or other abnormal physiological conditions may account for the lack of energy and ability of some of the failing students. Purdue University is planning to examine this possibility next year in hopes of finding new ways for remedying the deficiencies which lead to failures in freshman chemistry.

FRESHMAN DEFINITIONS

Chlorine—A dancer in a night club
Copper—A man who guards fire escapes at the girls' dormitory
Antimony—Fee collected by ex-wives smart enough to leave their husbands
Carbon—Storage place for street cars
Barium—What you do to dead people
Boron—A person of low mentality
Catalyst—A western ranch owner
Horse Sense—Stable thinking
Flask—Measuring vessel carried on the hip, graduated in fingers
Electrolyte—A thing which when it is dark you turn on and it gets bright

—From *The Kalends* of the Waverly Press

FORMULA OF THE MONTH

$$(NH_4)_2SiF_6 \cdot NH_4 \cdot F$$

AMMONIUM HEXAFLUOSILICATE—AMMONIUM FLUORIDE

This compound has the empirical formula $(NH_4)_3SiF_7$ and was first prepared by Marignac in 1859. X-ray analysis has shown the existence of seven-coördination complexes in a number of cases, such as the heptafluozirconates, containing the $ZnF_7^{=}$ ion. The analysis of this compound, however,[1] gave it the structure of a double salt, as the formula indicates.

[1] HOARD AND WILLIAMS, "Structures of complex fluorides," *J. Am. Chem. Soc.*, **64**, 633 (1942).

The Melting Point of Impure Organic Compounds[1]

EUGENE ALLEN *Stevens Institute of Technology, Hoboken, New Jersey*

IT HAS long been a familiar maxim in organic chemistry laboratory courses that the sharpness of the melting point is a good criterion of the purity of a compound; the shorter the range over which the compound melts, the purer the material. It is also well known that the melting point of organic compounds is usually depressed by impurities, the extent of the depression being conditioned by the amount of impurity present. However, the reason for these rules is not always clear to the student, despite the fact that they are of fundamental importance in the practice of organic chemistry, particularly in the determination of the purity of a preparation or the identification of a compound by the method of mixed melting points.

It is the purpose of this paper to make clear the principles involved in these two generalizations. A fundamental consideration of this topic leads to an understanding of the derivation of the ordinary "lens-shaped" diagram for the relation between transformation temperature and mol fraction in perfect solutions, and it explains the origin of the common eutectic type of phase diagram.

Let us start by considering two solids, A and B, with melting points T_A and T_B, respectively ($T_B > T_A$). A and B are assumed to form perfect solutions with each other both in the liquid and solid states.

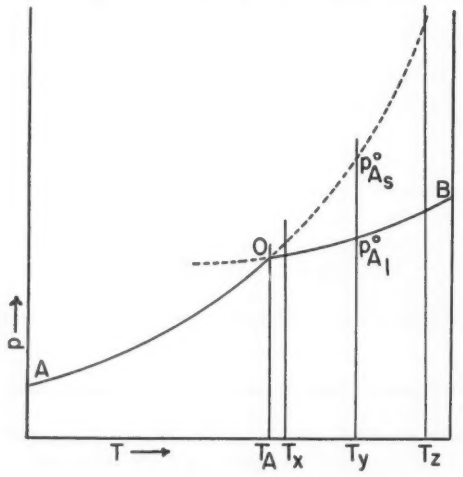

FIGURE 1

The vapor pressure–temperature curve for pure A is shown in Figure 1. AO is the solid–vapor curve, and OB is the liquid–vapor curve. Point O represents the transition from solid to liquid states. That the solid–vapor and liquid–vapor curves are discontinuous at

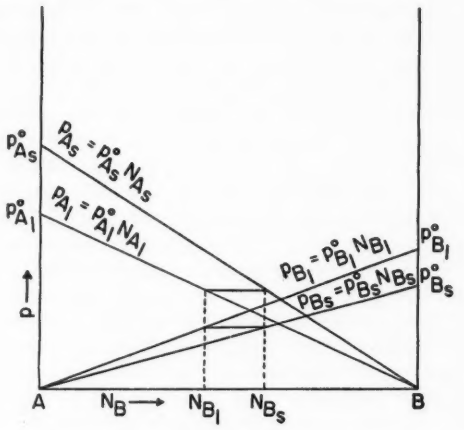

FIGURE 2

point O can be demonstrated by means of the Clapeyron equation:

$$\frac{dP}{dT} = \frac{\Delta H}{T \Delta V}$$

where ΔH is the heat of transformation of solid to vapor or liquid to vapor as the case may be, and ΔV is the change in volume occurring upon vaporization. Since ΔH is larger for S–V transformation than for L–V transformation, the slope of the curve, dP/dT, will be greater at point O for AO than for OB. The change in volume, ΔV, is not appreciably different for S–V transformation than for L–V transformation.

Consider a temperature T_y between T_A and T_B. At this temperature, designate the vapor pressure of pure liquid A by $p^0_{A_l}$ and of pure solid A by $p^0_{A_s}$. Since A and B form perfect solutions with each other the partial vapor pressures of both liquid and solid A in mixtures of A and B will be equal to the product of the vapor pressure of pure liquid or solid A and the mol fraction of A, as demanded by Raoult's law. This can be represented diagrammatically by the two lines

$$p_{A_l} = p^0_{A_l} N_{A_l}$$

and

$$p_{A_s} = p^0_{A_s} N_{A_s}$$

as indicated in Figure 2.

[1] Presented before the Division of Chemical Education at the 102nd meeting of the A. C. S., Atlantic City, New Jersey, September 11, 1941.

Now, in order for equilibrium between liquid and solid phases to exist, it is necessary that

$$p_{A_l} = p_{A_s}$$

which corresponds to drawing a horizontal line through Figure 2. We can see immediately that such a line will intersect the p_{A_l} and p_{A_s} curves at two different mol fractions, or in other words, at the temperature T_y it is necessary that the composition of the liquid phase be different from the composition of the solid phase with which it is in equilibrium. We would be justified in inferring from this that just as at every temperature there are two mol fractions corresponding to solid and liquid (provided that the temperature is between T_A and T_B, as will be seen later), in the same way for every mol fraction there must be two temperatures corresponding to solid and liquid. Put in another way, for any given mixture of A and B the temperature at which the solid will begin to melt will not be the same as the temperature at which the liquid will begin to freeze; there will be a melting point *range*.

In order to clarify the above statement and at the same time establish quantitatively the extent of the melting point range corresponding to any given mixture of A and B, we can proceed as follows: Draw a vapor pressure–temperature diagram for pure B, and locate the points $p^0_{B_l}$ and $p^0_{B_s}$. Since T_y is lower than T_B, the temperature vertical will cross the vapor pressure curves to the left of O, and as can be seen from Figure 1, $p^0_{B_l}$ will be greater than $p^0_{B_s}$.

We shall now determine the compositions of the liquid and solid phases in equilibrium with each other at

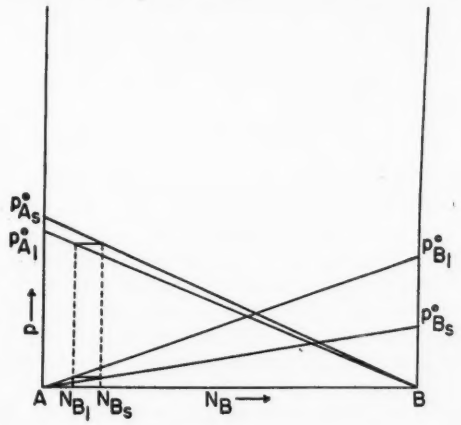

FIGURE 3

T_y according to the method of Seltz.[2] Draw in the curves

$$p_{B_l} = p^0_{B_l} N_{B_l}$$

and

$$p_{B_s} = p^0_{B_s} N_{B_s}$$

[2] SELTZ, "Thermodynamics of solid solutions. I. Perfect solutions," *J. Am. Chem. Soc.*, **56**, 307-11 (1934).

in Figure 2. For equilibrium between liquid and solid phases, we have the conditions

$$p_{A_l} = p_{A_s}$$

and

$$p_{B_l} = p_{B_s}$$

Obviously, however, N_{B_l} must equal $1 - N_{A_l}$ and N_{B_s}

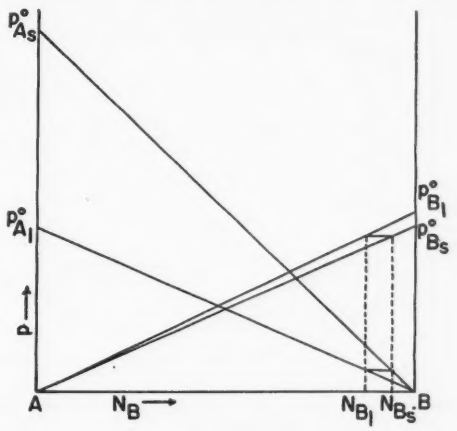

FIGURE 4

must equal $1 - N_{A_s}$. Inspection of Figure 2 indicates that the only values of N_{B_l} and N_{B_s} which fulfil these conditions are those indicated by the vertical dotted lines.

Let us repeat this process at another temperature, T_z, just slightly above T_A. As can be seen from Figure 1, $p^0_{A_s}$ and $p^0_{A_l}$ will be closer together than at T_y, but since on the P–T diagram for pure B the temperature vertical T_z will be even further to the left of O than T_y is, $p^0_{B_l}$ and $p^0_{B_s}$ will be farther apart at T_z than at T_y. Drawing the partial pressure diagram and proceeding in the same way as for T_y (Figure 3), we see that N_{B_l} and N_{B_s} will be close together and near the left of the diagram.

Repeating the process once more for a temperature T_z just slightly below T_B, we see that N_{B_l} and N_{B_s} are again close together, but this time near the right of the diagram (Figure 4).

If we plot all the values of N_{B_l} and N_{B_s} so obtained against the temperature, we obtain Figure 5. This diagram illustrates clearly the facts mentioned in an earlier paragraph, namely, that for every temperature between T_A and T_B the mol fraction of solid is not the same as the mol fraction of liquid with which it is in equilibrium, and also, for every mol fraction except 0 or 1 a definite melting point range exists. We can see also that as the composition approaches pure A or B, the melting point range decreases, and contracts to a single temperature when the pure compound is reached.

In passing, it should be mentioned that Figure 5 is entirely analogous to the familiar "lens-shaped" diagram of the distillation temperatures of perfect binary

solutions. It is a *phase diagram*, in that it indicates the limits within which the liquid and solid phases can coexist. Outside these limits (the interior of the

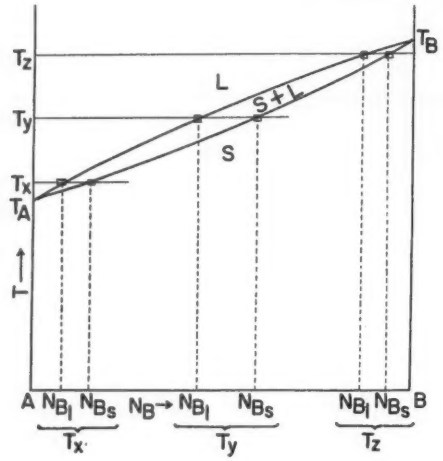

FIGURE 5

lens) we can have only pure liquid or pure solid. Equations for the upper and lower curves have been derived by Seltz.[2]

The foregoing has been developed on the premise that A and B form perfect solutions with each other. A perfect solution is one in which the atoms or molecules of the constituents do not interact with one another, the mixing of the two substances producing only a dilution effect. Raoult's law follows from this definition.

Deviation from Raoult's law is possible in two directions. The atoms or molecules of the constituents may exert a mutually attractive force, and each may tend

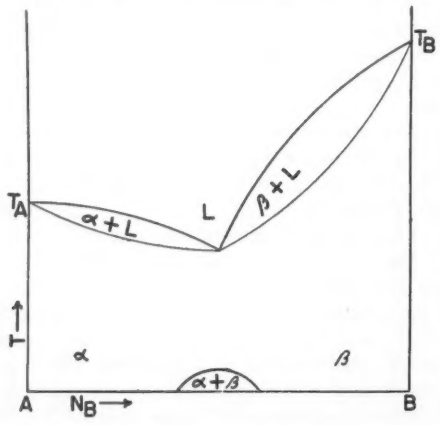

FIGURE 6

to prevent the other from vaporizing. For solid solutions, this will necessitate a higher temperature to produce a vapor pressure equal to that of the liquid, and the melting point will be raised. Or the atoms or molecules may exert a mutually repellent force, and tend to push each other out of solution. This will increase the vapor pressure, and therefore lower the melting point. Most organic solid solutions fall into this second category. The effect on the transformation temperature curve will be to produce a minimum, as can be seen in the upper part of Figure 6.

But when the net repulsion becomes pronounced, it will also manifest itself in a region of actual insolubility of solids A and B in one another at lower temperatures, producing a "solubility gap." The insolubility will decrease at higher temperatures. This is seen in the bottom part of Figure 6. From this point on, Greek letters will be used to denote the solid phases; α will denote that solid phase richer in A, and β that solid phase richer in B. In the case of complete intersolubility, of course, α and β will be continuous.

As the repulsive effect is further increased, the solubility gap becomes gradually higher and the minimum

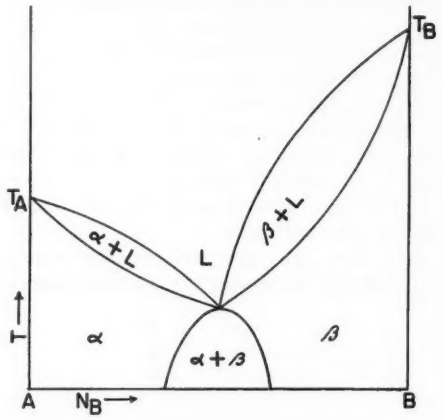

FIGURE 7

of the transformation curves gradually lower, until they finally meet at a point (Figure 7). This is an isolated but necessarily possible case. Going still further in the same direction, we arrive at Figures 8 and 9, which illustrate the genesis of the eutectic type diagram. If we go to the limit and assume absolute mutual insolubility of A and B, we will obtain Figure 10, which is the common eutectic diagram seen in elementary textbooks. It must be realized, however, that Figure 10 is a limiting case and is really incorrect, for no two substances show absolute mutual insolubility.

Since the great majority of organic solid binary mixtures fall into the eutectic class, let us consider in greater detail the changes which occur upon melting, referring to Figure 9. A will be considered as the substance under discussion, and B as the impurity. There are two possible cases.

The first possibility is that a sufficiently small amount of the impurity is present to exist in true solid solution in A. Considering composition N_1, no change of phase will occur upon raising the temperature until line $T_A a$ is

reached. At this point phases α and L (liquid) are in equilibrium. Upon raising the temperature infinitesimally above $T_A a$, the liquid phase appears having the

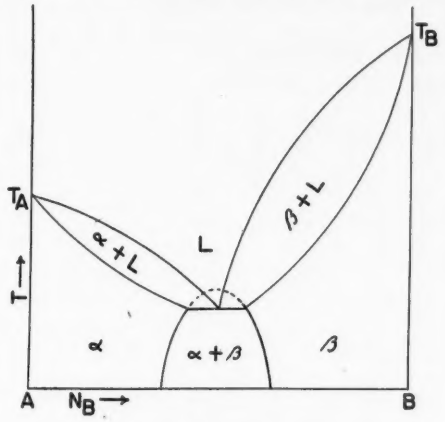

FIGURE 8

composition x_3. Since the liquid phase is richer in B than the original composition, the solid phase will be impoverished in B. But as can be seen by curve $T_A a$, decreasing the concentration of B will raise the melting point. At the resulting higher temperature, the process repeats itself. Thus, the solid phase will change along line $T_A a$ and the liquid phase along line $T_A o$, the two phases in equilibrium being connected by horizontal lines or "tie-lines." To find the relative

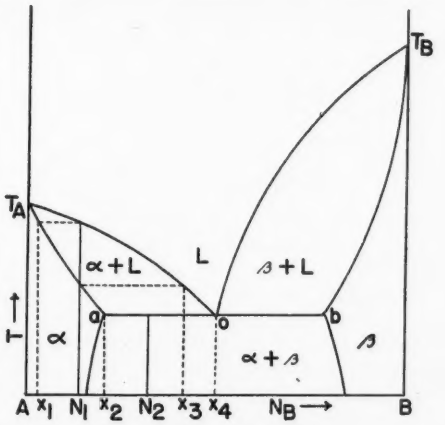

FIGURE 9

amounts of the two phases present at any temperature, draw the tie-line and consider it as a lever, with the composition vertical N_1 as the fulcrum. The relative amounts of the two phases α and L will then be inversely proportional to the distance between the corresponding end of the tie-line and the fulcrum.

Upon reaching $T_A o$, the solid phase is exhausted, the last solid to exist having the composition x_1. This is the end of the melting point range, but the temperature is nevertheless lower than the melting point of the pure substance.

The second possibility is that too large an amount of impurity is present to dissolve in A, and two solid solutions exist in equilibrium with each other. This case is the same as the first, except that melting always starts at the eutectic temperature. Considering composition N_2, no change of phase occurs until line *aob* is reached. At this point a three-phase equilibrium exists between α, β, and L. Upon raising the temperature infinitesimally above *aob*, the liquid phase

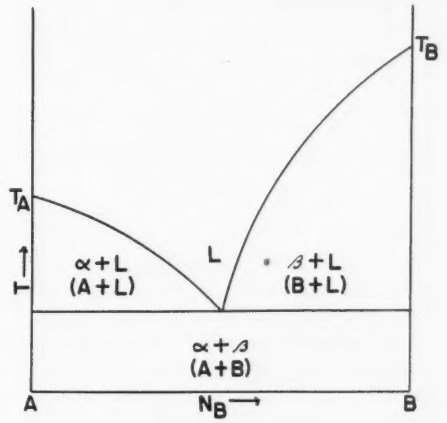

FIGURE 10

appears having the composition x_4, and the β phase disappears. The α phase has the composition x_2: the rest of the transformation is analogous to case 1.

Not all organic solid binary mixtures belong to the eutectic type. Several cases are known in which the melting and freezing curves lie entirely between the melting points of the pure constituents (similar to Figure 5). The *d*-carvoxime–*l*-carvoxime diagram shows a maximum in the curves. This type of diagram is rare.

An interesting pair of substances is the system composed of the optically active oximes of camphor. These two substances not only form perfect solutions but also have the same melting point and are completely intersoluble. They are therefore thermodynamically indistinguishable, and the S–L transformation curve is a single horizontal line.

SUMMER CHANGE OF ADDRESS

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Color Nomenclature in Qualitative Analysis

I. The Inter-Society Color Council Nomenclature[1]

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COLOR nomenclature in chemistry is not on a scientific basis at the present time. Down through the years, text and reference works have confused the student by such terms as flesh pink, salmon pink, brick red, cherry red, blood red, wine red, magenta, sky blue, canary yellow, and even blackish white. To confound the confusion, the same name is often assigned to different colors and different names to the same color. A commonplace and rigorous nomenclature is certainly needed.

Color is one of the important physical properties studied in a course on qualitative analysis. The progress of many separations is followed by observance of color changes and most confirmatory tests are based upon the formation of colored substances. The identification tests for 80 per cent of the cations usually studied result in colored derivatives.

It is well known that a student's success in qualitative analysis depends, in a large measure, upon his knowledge of the colors of substances encountered during the analysis. This knowledge includes the association of a color or range of colors with a particular substance, the designation of the color with simple though descriptive color names, the acquaintance with the variations in color caused by variations in experimental conditions, and the ability to describe an observed color in elementary yet meaningful terms.

A comparison of color names found in various standard books on inorganic qualitative analysis leads to the conclusion that these names are neither consistent nor truly descriptive. For instance, the color names, brown, crimson, and brick red given for the cobalt complex formed with alpha-nitroso-beta-naphthol cannot all be truly descriptive of the substance. Such color names as lemon yellow, apple green, and strawberry red are pleasant sounding but bring different colors to the mind of the reader, depending on his past experience. Ware, in the introduction to his text on qualitative analysis (*1*), has aptly described the situation:

> "You may be an expert in color, but to interpret the many time-worn expressions customarily used in an attempt to assist the student in visualizing a forthcoming flame test, colored solution, or colored precipitate would require an intimate knowledge of the birds of the air, the flowers of the field, and various building materials, as well as a sense of humor. An examination of the following list will make the point clear: canary yellow, lilac lavender, straw colored, brick red, reddish brown, brownish red, orange, carmine, and the gem, especially if you are in a cosmopolitan class, is flesh color."

[1] Presented before the Division of Chemical Education at the 103rd meeting of the A. C. S., Memphis, Tennessee, April 21, 1942.

Twelve years ago, in a short discussion on color names in analytical chemistry (*2*), Yoe pointed out that, "the color name problem can be solved most successfully by the use of standard color plates. Ware has made an excellent step in this direction" (*1*). This attack on the solution of the problem by the use of color reproductions of solids, liquids, and flames is a definite step forward; but even if color plates are used we still need satisfactory color names to designate the colors.

There seem to be some practical difficulties involved in the use of color plates for students. The cost of color standards satisfactorily to represent the colored substances in all their variations, as encountered in the laboratory, would probably be prohibitive. The chief difficulty the student encounters in the use of color plates is the deviation in the color of a substance from the reference color. For example, he obtains a substance which should have a color matching that of a certain plate; but on comparison of the colors, he finds that they do not match, even though the substance is definitely known to be the one described. The nonmatching may be due to faulty color reproduction of the plate, differences between the surfaces of the plate and the substance, the method of observation, the kind of illumination, and variation in color of the substance with conditions of formation.

However, color plates or standards are not required by the student. He does need a set of suitable color names so that he can associate a clear, meaningful name with an observed material and use the name to describe it. If, due to difference in experimental conditions, different colors are observed for the same substance, then correspondingly different color names should be given for that substance, and the conditions causing variation in color should be specified, or at least indicated. The association of a particular name with a particular color modification should be easily and unquestionably accomplished.

Color names should be truly descriptive. They should not only recall the colored substance to mind but also should convey the approximate color to the minds of others. The names should not be confusing but should be logical and easily understood. They should be limited in number and consist of simple, suggestive words so that they can be remembered easily. The names should represent the same color range, regardless of the material designated or the field in which they are applied. They should belong to a uniform, widely used system of nomenclature.

A logical, understandable color naming system has been developed and is gaining wide use and recognition.

This system is designated as the ISCC-NBS color naming system. The letters represent, "Inter-Society Color Council—National Bureau of Standards." Since it is believed that very few chemists are acquainted with this system, and since it has been found so satisfactory for the identification of colors of substances encountered in qualitative analysis, this brief description is presented.

In 1921, the United States Pharmacopoeial Revision Committee clearly recognized the jumbled state of color nomenclature in the field of pharmacy (*3*). The confusion was similar to that in the field of chemistry. Subsequent study of color nomenclature by interested persons resulted in the formation of the Inter-Society Color Council in 1931. This council consists of voting delegates from the following national organizations: American Association of Textile Chemists and Colorists, American Ceramic Society, American Psychological Association, American Society for Testing Materials, Illuminating Engineering Society, National Formulary, American Pharmaceutical Association, Optical Society of America, Technical Association of the Pulp and Paper Industry, and the United States Pharmacopoeial Convention. The American Chemical Society is not a member.

At the first meeting of the council in 1931, Dr. E. N. Gathercoal, speaking for the United States Pharmacopoeial Revision Committee, presented the problem of selecting a system for designating color (*4*):

"... such designation to be sufficiently standardized as to be acceptable and usable by science, sufficiently broad to be appreciated and used by science, art, and industry, and sufficiently commonplace to be understood, at least in a general way, by the whole public."

The council referred the problem to its Committee on Measurement and Specification. In 1933, after several reports of various systems of color designation, the committeee presented the outline of a system that was considered to be very satisfactory. This system was then developed by D. B. Judd and K. L. Kelly of the National Bureau of Standards (*4*). It was unanimously approved by the Inter-Society Color Council in 1939 and is now known as the ISCC-NBS color naming system.

The Munsell color system is the basis for the ISCC-NBS method of color designation. This system, originated in the early part of the twentieth century by A. H. Munsell,[2] fulfils a double requirement of color specification. It designates color as perceived by an observer and relates it to the psychological color solid, schematically shown in Figure 1. A color may be uniquely described by the three attributes: lightness, saturation, and hue. Lightness, or value, indicated by the vertical axis, distinguishes light colors from dark; saturation or chroma, represented by the horizontal axis, distinguishes brightly colored substances from those with gray or neutral tones; and hue, represented by the angle about the vertical axis, distinguishes one color from another, *i. e.*, represents the dominant wave length that is reflected or transmitted.

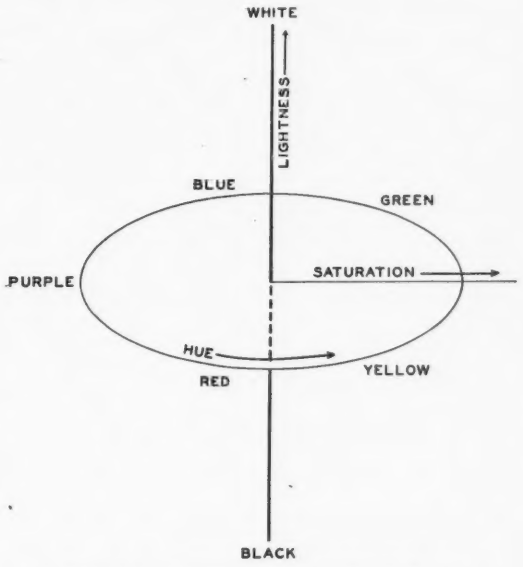

FIGURE 1.—DIMENSIONS OF THE COLOR SOLID

According to the Munsell system, the value scale is divided into 10 equal parts; a value of 0 is assigned to black, 5 to neutral gray, and 10 to white. The chroma scale extends from 0 for a color devoid of hue, to the practical limits determined for each hue by the pigments available. The Munsell system contains no chroma above 14. The hue circle is divided into 100 equal parts. There are 10 principal hues: red, yellow red, yellow, green yellow, green, blue green, blue, purple blue, purple, and red purple forming a complete circle as shown in Figure 2. Each principal hue is designated by the number 5 before the symbol for the hue name. The hue steps decrease to 0 in the counter clockwise direction and increase to 10 in the clockwise direction. A Munsell notation, relating a color to the psychological color solid and identifying the color, consists of a letter accompanied by numbers. For example, the notation 4 R 3/6 designates a color having a hue of red, a value of 3, and a chroma of 6. This color is red with a slight tendency toward purple, fairly dark, and only moderately saturated.

The Munsell Book of Color (*5*) consists of color chips scientifically prepared to represent the various hues, values, and chromas. These chips may be visually compared to a substance to determine the Munsell notation of its color. The three different arrangements of these color chips are designated as charts of constant hue, constant chroma, and constant value. There are 20 constant hue charts, one for each of the principal and secondary hues. A constant hue chart consists of color chips representing each two steps of value and each two steps of chroma. The constant chroma charts consist

[2] *J. Optical Soc. Am.*, **30**, 573–645 (1940), contains a series of five papers covering the history and evaluation of the Munsell system.

of chips representing each two steps of value for each of the 20 hues. The constant value charts consist of chips representing each two steps of chroma for each of

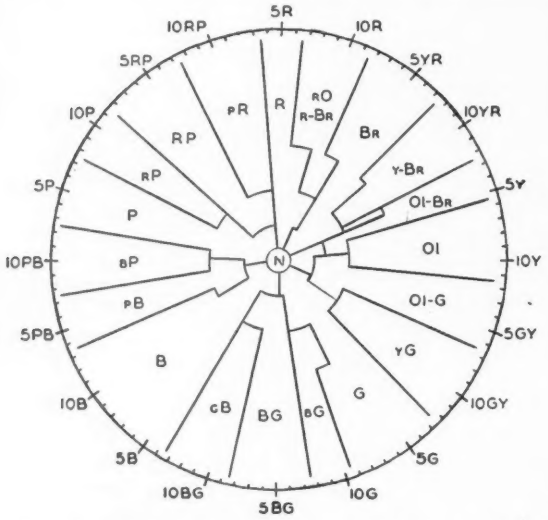

FIGURE 2.—HUE CIRCLE FOR DARK AND MEDIUM COLORS

the 20 hues. The Abridged Munsell Book of Color (*5*) is made up primarily of the 20 constant hue charts, which are sufficient for color identification.

The numerical Munsell notation did not satisfy the needs of the groups represented by the Inter-Society Color Council. Consequently, representing the Munsell hues by commonly used color names, they established a logical system of modifiers to represent the numerical coördinates of value and chroma. This system of modifiers is illustrated by the chart shown in Figure 3. "Light, moderate, and dark" are used to designate increasing darkness; "weak, moderate, and strong," to designate increasing saturation. Each scale is expanded in both directions by the use of the adverb "very." The substitutions shown in the chart, such as "brilliant" for "light strong," are made in order to avoid long unwieldy names. The ISCC-NBS names consist of these modifiers accompanied by the following hue or limited hue range names: pink, red, orange, brown, yellow, olive, green, blue, and purple. Combinations of these hue names such as "blue green" or "purple blue" are used to define a larger number of colors.

In 1939, Judd and Kelly of the National Bureau of Standards published 34 boundary name charts which consist of 319 color names covering all possible Munsell notations (*4*). These were prepared by grouping the 100 Munsell hue divisions into 34 groups in such a manner that a single name could be applied to all of the hues in the group for any given value and chroma area. The boundary name chart for the Munsell hues, 3 P to 7 P, is shown in Figure 4.

Since the trained human eye can distinguish 10 million different colors, each of the 319 color names represents a group of about 30,000 distinguishable colors. However, a numerical system, such as that recommended by the International Commission on Illumination (*6*), should be used when it is necessary to make careful distinctions. The Munsell standards and consequently the ISCC-NBS names have been related to this numerical system by Glenn and Killian (*7*). As a result of the limited number of color names, two noticeably different colors may have the same name whereas two scarcely distinguishable colors may have different names. For example, if the colors of the substances A, B, and C are plotted on a boundary name chart and if A falls just across a name boundary from C whereas B falls farther away from A but in the same name area, it is obvious that A would be more nearly similar to C than to B; however, A and B would receive the same color name while A and C would receive different names. This disadvantage always results when arbitrary boundaries are established.

Judd and Kelly, in discussing this, write (*4*):

> "Analogous disadvantages result from identifying the time of events according to date; two events occurring on the same date may be separated by many hours, but on the other hand two scarcely separable midnight events may have to be assigned different dates."

In spite of this, identifying the date of an event has proved useful.

The system of color nomenclature, as originally established for opaque finely divided solids, has now

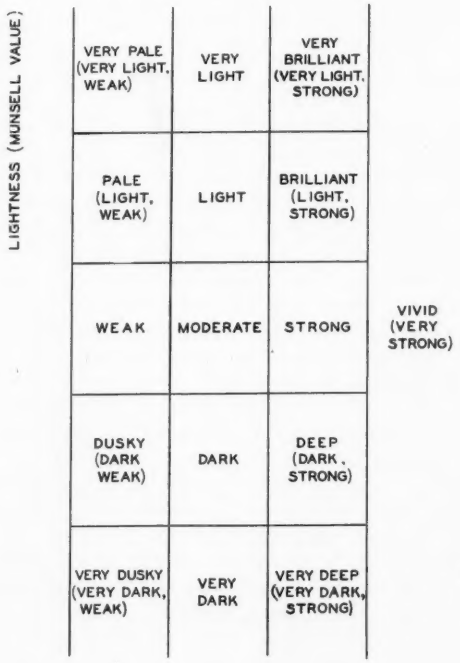

FIGURE 3.—SYSTEM OF MODIFIERS

been applied to whole crude drugs; microscopic structures; clear liquids; clear crystals, glass, and resins; translucent or cloudy solids and liquids; and fluorescent liquids. The following name modifications are necessary to apply the system to substances viewed by transmitted light (*8*).

Substitute:

colorless for white
faint pinkish (color) for pinkish white
faint greenish (color) for greenish white
faint bluish (color) for bluish white
faint purplish (color) for purplish white

The hue only of a liquid, transparent crystals, microscopic structures, translucent or fluorescent materials should be designated. The full color name should be given for any commercial liquid whose color is to be held constant.

The color of a finely divided opaque solid is identified in the following manner. The sample is placed slightly heaped up in an aluminum holder containing a depression of at least 2-mm. depth. An optical cover glass is placed over the sample with a rotary motion, to pack the material tightly, and clamped in place with rubber bands. Only light reflected by the solid should be observed.

The sample and comparison charts are illuminated by diffuse daylight or by a suitable artificial source. It is most desirable that the light fall on the sample at an angle of 45°, from the left of the observer, and that the sample and charts be viewed directly from above (*6*). A black canopy hung above the sample and opposite the observer prevents the reflection of light by the cover glass. The sample and charts can be illuminated from directly above and viewed at an angle of 45°. In this case the canopy is on the side of the sample opposite the observer.

The sample is placed under the center opening of a tri-apertured neutral gray comparison mask. The two adjacent constant hue charts, between which the hue of the sample lies, are chosen. The value is determined by moving the charts up and down, varying the value, and estimating it to the nearest 0.1 of a division. By moving the charts horizontally, in the direction of varying chroma, the adjacent chroma values, between which the sample lies, may be chosen and the chroma read to the nearest 0.5 of a division. The approximate hue is then obtained by comparing the sample with the color chips of the nearest value and chroma; the final hue is estimated by interpolation to the nearest hue division. After interchanging the two standard comparison charts and checking the hue and value, the Munsell notation is recorded. If the illumination is not uniform, inconsistencies will be obtained when the charts are interchanged. The color name is then determined by plotting the value and chroma on the boundary name chart corresponding to the hue of the sample. For example, if the Munsell notation is 5 P 4.5/10.0 the color name is strong purple as determined by plotting the value and chroma on the chart shown in Figure 4.

The color names of translucent liquids are determined in a similar manner using transmitted light rather than reflected light. A vial made from a small Nessler tube, and etched at a distance of one cm. from the bottom,

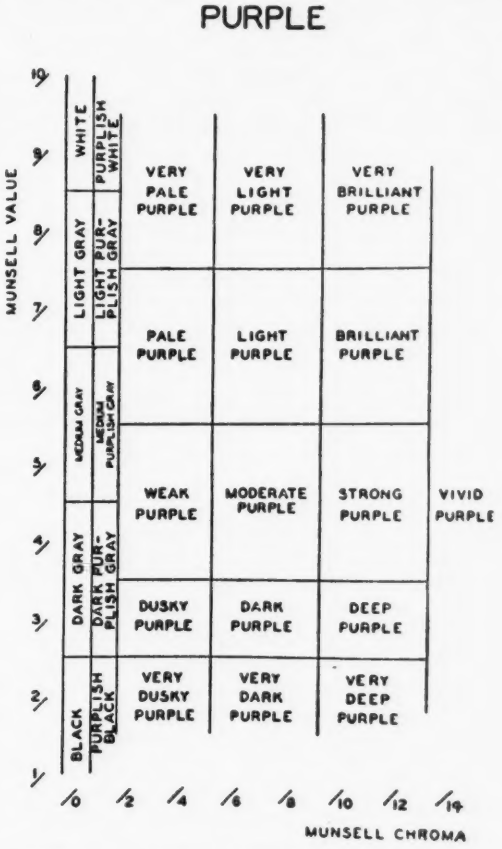

FIGURE 4.—BOUNDARY COLOR NAME CHART FOR THE MUNSELL HUES 3 P TO 7 P

is filled to the mark with the liquid whose color name is to be determined. The vial is placed in a brass holder containing an opening at the bottom equal in area to the apertures in a white comparison mask. The apertures are surrounded by a black area. Then, by holding the sample about eight inches above the white mask, and looking down, through the liquid, the sample may be identified with the correct Munsell color chips, as described above. In most cases, because of the variation of the colors of solutions with concentration, notation of the hue is sufficient. Even then the concentration range should be specified.

Whether all of us accept and use the ISCC-NBS system or not, we must acknowledge the fact that most of the large scientific organizations interested in color have approved the system and that it is recommended by the National Bureau of Standards. The American Chemical Society is one of the large groups to which color nomenclature is important that has not approved the system. Regardless of this situation, it should be

realized that many of our students will subsequently work in fields where the ISCC-NBS color nomenclature is employed and that they should become acquainted with the names in their undergraduate work. The standard color names are given to us in theory, but, in order to have them in fact, they must be applied.

The ISCC-NBS method of color designation has been applied to qualitative analysis and the authors' students have used the color names in a preliminary way. The results of the color identification studies and the use of the standard color names by students will be reported in a later paper.

ACKNOWLEDGMENT

We wish to express our gratitude to Professor M. G. Mellon who suggested the possibility of the use of the ISCC-NBS nomenclature in qualitative analysis, and to thank D. B. Judd and K. L. Kelly for their kind permission to reproduce the figures appearing in this article.

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ON A SUGGESTED REVISION OF THE SEVENTH PERIOD OF THE PERIODIC TABLE[1]

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IN THE generally accepted classification of the Periodic Table, elements 87, Ra, Ac, Th, Pa, and U, which make up the seventh period, have been placed successively and occupy subgroups (*a*) of Groups I, II, III, IV, V, and VI. No objection can be raised regarding the location of the first three elements of this period; on the other hand, the analogies characteristic of the Periodic Table cast some doubt as to the location of the following elements.

In the first place, the similarity of periods 2 and 3, 4 and 5, suggests a possible analogy between periods 6 and 7. This analogy is confirmed if account is taken of the sequence of atomic numbers of the noble gases, in which the difference between two consecutive atomic numbers corresponds to the number of elements contained in the period between them. This sequence is made up of the numbers:

$$2, 10, 18, 36, 54, 86, \ldots Z_p$$

where Z_p is the atomic number of the noble gas at the end of the p^{th} period, and

$$Z_p = 2p(2 \times 1 - 1) + 2(p-1)(2 \times 2 - 1) + 2(p-3)(2 \times 3 - 1) + 2(p-5)(2 \times 4 - 1) + \ldots + 2(p - 2n + 3)(2n - 1) \quad (1)$$

This expression, in which only the positive terms should be considered, corresponds to the law of formation of the extra nuclear electronic shells of the noble gases in accordance with Bohr's ideas, where the numbers *1, 2, 3, 4,* . . . correspond to the terms *s, p, d, f,* . . . . For example, the fourth period would be completed with the element of atomic number Z_4, *i. e.*,

$$Z_4 = 8_s + 18_p + 10_d = 36$$

Bearing in mind Pauli's exclusion principle, and expanding the previous expression, we have for this element the following electron configuration which coincides with that suggested by Bohr for krypton:

$$8_s + 18_p + 10_d = K_s^2 + L_s^2 + M_s^2 + N_s^2 + L_p^6 + M_p^6 + N_p^6 + M_d^{10}$$

If we calculate by means of formula (1) the atomic number of the element which would complete the seventh period, we obtain

$$Z = 118$$

which coincides with that found by Bohr for the nuclear charge of the seventh noble gas. This conclusion, which is based on the close similarity which characterizes all noble gases, leads to the assumption that period seven has 32 elements, just as the sixth period. If the sixth and seventh periods are made up of an equal number of elements, they should have identical configurations and therefore there must exist in the seventh period an array of 15 elements similar to the rare earths which, by analogy, should occupy the place reserved so far for actinium alone ($Z = 89$).

On the other hand, J. Perrin, bearing in mind the similarity between lanthanum and actinium, has suggested the possibility that in place of actinium there should exist a second series of rare earths. The probable existence of this new array of elements will force a revision of the final part of the Periodic Table.

If it is accepted that the atomic numbers of thorium ($Z = 90$), protoactinium ($Z = 91$), and uranium ($Z = 92$), are correct, then it would be necessary to move these elements to the place now occupied by actinium, while if the present location of such elements is correct, then their atomic numbers should be raised by 14 units.

[1] *Cf.* VILLAR, *Ann. Acad. Brasil. Sci.*, **12,** 51–7 (1940); MAYER, *Phys. Rev.*, **60,** 184–7 (1941).

Glass

F. C. FLINT *Hazel-Atlas Glass Company, Washington, Pennsylvania*

DEFINITION

WE ALL have a general feeling of knowing what glass is without having a clear definition of it. We do appreciate, however, that glass is always a product of fire. It is a ceramic product, produced from inorganic materials which have been melted together and cooled until they produce a hard substance which appears to be, and is, truly an undercooled liquid. That is, it is not crystallized.

Glass is usually transparent, but there are black glasses, made by putting in enough color to exclude the light. Sometimes intentional impurities are put into the glass to give internal patterns. Some of the chemistry involved in producing these various effects is very interesting. This reaches into the fields of colloidal chemistry, solutions of materials, and even into the molecular patterns of the glass itself.

Some organic substances imitate glass in one or more of its properties. They may be clear and transparent, they may show somewhat the play of light and colors; but they do not have the permanence or hardness or weight or feel which makes us pick up an article and call it glass because it to us is glassy.

Glass making may be divided into several subjects:

1. Mixing dry, raw, earthy materials.
2. Melting.
3. Forming the article or shape desired.
4. Annealing to relieve strain.
5. Chemical and physical properties of the finished article and methods of test.

All the equipment used and tests made are for furthering one of the above five objects.

The equipment that is used in modern glass factories is quite elaborate because to the hand methods developed over the centuries have been added many recent mechanical and engineering improvements. It is here in fact that most of the modern advances in technology have been achieved.

1. MATERIALS FOR GLASS MAKING

Glass is a commercial material, and the uses to which it will be put determine the type of glass to be made. These uses are in part developed by the desires of the user and the ability of the glass manufacturers to create a glass which will answer the purpose. That glass is so common is due to its ability to fulfil many demands economically. Generally, these demands may be classified as follows:

Cost

For common use, glass must be cheap; even expensive, special items, such as optical lenses of particular properties, are used more when they do not cost too much. Drinking glasses, or tumblers, are made by the millions now, because they answer the demand for a clean, convenient article from which to drink, which is obtainable at a low cost. In the ancient days of limited art craft, only a few could afford glass. It ceased to be a luxury when it became cheap. Even in our grandmothers' day, tumblers were so valuable that jelly glasses were saved for drinking glasses. Now, we obtain them in the five and ten cent stores.

Composition

Most commercial glass is made of sand, soda, and lime:

SiO_2	70%–75%
Na_2O	12%–19%
CaO	5%–14%

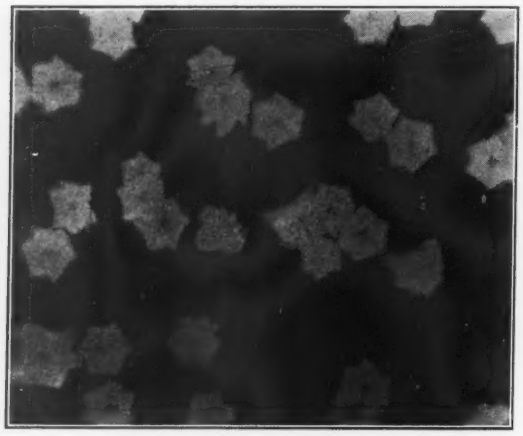
Oftentimes, other materials are added, such as magnesia, alumina, boric oxide, lead, zinc, etc., to vary the melting behavior or the chemical or physical properties of the glass.

Glass, like any natural silicate, when it cools from the molten state, reaches a temperature at which it wants to crystallize. This is generally prevented by taking advantage of the fact that the glass gets stiffer on cooling, or, as the physicist would say, it increases in viscosity. We can make use of this property by cooling it rapidly enough that crystallization cannot start. In other words, we pass through the freezing zone without letting the glass freeze into crystals as most liquids do. Sometimes small amounts of materials are put in to develop certain types of crystals embedded in the glass, but basically, the glass itself must not crystallize.

The study of these necessary temperatures and the type of crystals that can be obtained is a very elaborate one, based on the "phase rule." The work of melting the glass above the temperature at which the glass will crystallize, making formulas which will not crystallize too readily, and then cooling at the proper rate of speed is all part of this very important study.

There are several ways of considering glass, to understand why the material makes such a useful article of commerce. One way is to consider it as a kind of rock. Geologically, all igneous rocks were once molten. As the earth cooled, these rocks hardened and crystallized, so we have the granites, the syenites, the feldspars, quartz, and all the so-called igneous rocks; but sometimes from the interior of the earth came to the surface some of the molten material which, as it rose, cooled too rapidly to crystallize. Part of this behavior came from the fact that that particular part of the molten material

had a composition such that it became quite viscous (like molasses in January) and did not crystallize so readily as the igneous rocks, which not only wanted to crystallize, but had a longer time in which to do it and more fluidity to permit crystallization.



Courtesy of the Journal of the American Ceramic Society
CRYSTAL FORMATION AT 973°C.
Magnification 17×

One of these natural glasses is called obsidian, found in large quantities in some of our western states. A typical analysis is not unlike a glass analysis:

SiO_2	75%
Al_2O_3	10
Fe_2O_3	4
CaO-MgO	2
Alkalies	8

Obsidians are like the great lava flows from the active volcanoes. These are just as good glasses as we manufacture, except they contain a considerable number of impurities which make them colored—and we desire good, transparent bottles. Therefore, we can consider the glass which we make as an artificial rock and the furnace we use as a very small volcano. We have just taken the tremendous forces of heat and energy involved in volcanic action, which makes lava, and placed them under accurate control. The glass we produce is then blown, generally in machines nowadays, though still frequently by mouth, thus making a bottle out of a liquid rock.

Another way of considering glass is from the standpoint of its manufacture and use, as determined by the properties of the chemicals out of which it is formed. The perfect glass bottle would be made of silica, which we know as quartz. The difficulty is that silica is very hard to melt, the temperature being nearly 3100°F., and it is extremely hard to manipulate at that high temperature. So, theoretically, the first glass blower decided on trying to use silica and thought he had a wonderful idea. He could make bottles and articles of commerce out of the material, but it was nearly impossible to melt and blow into shapes. Our mythical inventor then turned to adding a material to this silica so that it would lower its melting point to get the glass down to a temperature at which he could handle it, just as alcohol would be added to water to lower the temperature at which it would freeze in the radiator of a car.

The material which was added was soda. It did just what it was supposed to do, and lowered the temperature at which the glass melted; but it introduced another difficulty. The whole thing dissolved in water, and one good property of the silica was lost. It was no longer useful as a container for liquids.

Of course, our mythical inventor had discovered water glass, and continued to make some of this soda-silica mixture and sold it for glue. He really developed a very large and useful industry, but he was not content for he still had not found the material that would make glass bottles and windows. On looking further, he found that by adding some limestone to the soda and silica, the temperature of melting did not go down much more, but the limestone seemed to help the glass to resist dissolving in water. The glass was still able to stay fluid enough so that it could be gathered on the end of a blowpipe and shaped before it got too stiff to move. He then found that by cleaning his materials really well and adding small quantities of other ingredients, he could change the color or some of the physical or chemical properties to a small extent. He had discovered glass and founded the industry which to us means windows, containers, spectacles, and the host of glass articles that are part of our daily life.

These other ingredients are very interesting. Of course, they are all inorganic substances, oxides of elements that are listed in the Periodic Table. Properties of the glass that are contributed by these materials are often partially predictable by this table.

MAJOR INGREDIENTS

Silica

The glass as made by our mythical inventor started with silica, which represents the biggest part of the glass. In the ultimate analysis, silica is about three-fourths by weight of most glass. This silica usually comes from quartz sand. This is generally obtained only in quarries where the sand is naturally very clean and where the grains can be easily broken apart and washed. Sometimes the sand can be shoveled up with a scoop shovel, but more often the sand grains have been cemented together with silica or lime or iron or clay, with a result that it forms a sandstone which must be blasted out with dynamite. The lumps of sandstone are then broken, with a crusher that looks like a big, brutal coffee mill. This breaks the stones down to one- or two-inch size or smaller. These stones are then washed with water on to a mill, generally a "chaser mill," in which two big, heavy rollers chase each other around in a large pan. The weight of these rollers breaks the sand grains apart from each other, and with the help of plenty of water, the individual grains are then sent down a chute and into a washing system.

The grains of sand then come through as clean, white quartz. If the sandstone naturally is very pure quartz and all the impurities are between, and not inside the grains, this makes a good grade of sand for glass use.

This sand is then sieved through a 20-mesh screen so as to take out larger particles that would be slow to melt, and the water takes away the dust. The resultant sand is generally well over 99 per cent pure.

The iron content, expressed as iron oxide, is generally under three-hundredths of one per cent (0.03%). For extremely color-free glass, sand may be desired in which the iron is down to one-hundredth of one per cent (0.01%), or one part in 10,000. This is because iron is a powerful colorant in glass.

Boron

In substituting other materials for silica, boron oxide could be used. Most of it comes from Southern California from those very interesting old lake deposits which have produced as many chemicals as the Stassfurt beds in Germany. A small amount of boron oxide is added to a good many glasses, but it is in the heat-resistant glass that it is most valuable. It is a costly ingredient, very good for making glass able to withstand rapid changes in temperature, or, technically, to lower the coefficient of expansion. Boron oxide is often also added to help lower the melting range.

Phosphates

Phosphate glasses are not so common, except when special physical properties are desired. Certain opal glasses and optical specialties use the little that is made. Phosphate used to come from bone ash and as such carried a number of other impurities. Now it is a by-product of the fertilizer industries' reduction of apatite rock.

All these above ingredients provide the acid radicals in the glass. These ingredients form the framework, or lattice, that makes the glassy state. They do this because the molecules in joining together do so in a random condition which does not make a regularly repeated pattern which would be a crystal. The joining together of several of the atoms makes groupings large enough and bonded tightly enough to reduce the mobility so that crystals cannot form so readily when they want to. Most of the other ingredients that are in glass, except the alumina and a few rare ones, do not fit into this lattice as a part of it, but take their places in the spaces left open in the lattice. By their presence, they change the physical properties one way or another according to the characteristics of the element introduced and its ability to influence the lattice structure or to combine with other ingredients.

Alumina

Another material which acts to help make glass is alumina. Years ago glass blowers realized that some of the glass tubing made in Thuringia, Germany, could be reheated a number of times without crystallizing or showing a scum on the surface. It was later discovered that the sand naturally had considerable alumina in it. It was a good many years before it was realized that the alumina was responsible. Now, alumina is added to a great deal of glass, usually as a mineral such as feldspar, which is a sodium- or potassium-aluminum silicate, or nepheline, another similar mineral. There are a good many combinations of alumina used in the glass "batch," as the unmelted mixture is called, the chief considerations being freedom from iron, uniformity of analysis, and cost.

Soda Ash

As our mythical glass man used soda up to 15 per cent or 18 per cent of the ultimate composition, so the industry is still using soda ash, commercial sodium carbonate. It is all made by the Solvay process. The production of soda ash from brine is an industry in itself, producing about a million tons a year every year for the glass industry alone.

Potash

One of the minor ingredients used is potash. It is used sometimes with soda or for special glasses. The quantity used, compared with soda, is very much smaller, and it comes from natural brines in the West. The production of potassium carbonate is also a very special industry.

Potash is often used either to replace the soda, or with it, to help the chemical durability of the glass, that is, the resistance of the glass to attack by chemicals. It makes the viscosity of the glass higher, or in common words, the sirup more thick.

Lithia

Lithia as an alkali is also used in some glasses. Its effect on the physical properties is quite predictable by its position in the Periodic Table. Its small molecular weight makes a given amount more effective, and its position makes it more liable to crystallization and changes its effect on the viscosity of the melt, a very important thing in "working" the glass.

Lime

In order to harden the glass, our mythical glass man used calcia or lime. He could have used either dolomite or magnesia or baryta.

Calcium oxide, and magnesium oxide, represents 8 to 10 per cent of the glass. Sometimes it is added as burnt lime, and it used to be added as slaked lime, which is the hydrate. A good portion of the lime used is the original stone, calcium carbonate, or calcium-magnesium carbonate, dolomite, because the heat in the glass furnace will drive out the carbon dioxide. Both dolomite and high-calcium limes are used, and it seems to make little difference whether or not the magnesium is there. The main consideration again, as with sand, has to do with the amount of iron that is found. For real transparency, as in optical glass, precipitated calcium carbonate may be used in order to eliminate impurities.

Barium; Lead

Barium oxide influences the index of refraction, which helps to make the glass sparkle. Lead oxide does even more so, and it makes the glass melt at a lower temperature. These have made a lot of compositions possible that produce the ranges of optical glass which make available the large variety of very valuable instruments.

COLOR INGREDIENTS

Iron Oxide

All of these would have made a complete glass, but of a slightly greenish color, due to the iron which is one of the ever-present impurities. Iron oxide is usually kept very low because of this greenish cast, which you see in the old-fashioned fruit jars and most of the antique bottles. However, it is sometimes added when a green color is wanted. It is unfortunate that we do not want this green color more often, for iron is a good assistant in melting the glass, and in preventing crystallization.

Minor Ingredients

Then, to make glass more interesting, we might add iron, chromium, manganese, uranium, and other materials. Chromium is added to make the glass yellow-green; copper, blue-green; cobalt, blue; manganese for purple; uranium for yellow. The chemistry of colored glasses is very complex. Some minerals produce their effect in the glass as solutions, others as colloidal suspensions.

The minerals which color glass by going into solution as compounds, the iron, copper, chromium, cobalt, etc., make very much the same colors that they do in combination with other acids than silica. We are familiar with these colors in the laboratory. Just as these minerals give slightly different colors with different chemical combinations, for example, the various copper salts, so two different glass compositions can vary the shade of the color produced. This is another part of glass manufacture and its science in which the glass may be made more or less acidic to vary the color, or in which different bases may be used to influence the color.

The colloids produce color for a very different reason; the extremely small particles filter or scatter the light transmitted by the glass. Colloidal gold is an example; its colors are very much the same in glass as in water. Gold ruby is used for very fine glasses.

Clarifiers

For clarifying the glass, or to assist in melting, sodium nitrate, arsenic, or salt cake are used. These materials are either volatile in themselves or have volatile constituents which are used to take out carbon impurities as they bubble through the glass on their way out themselves. Carbon itself burns when it is on top of the glass, but down in the glass there is nothing more stable than a carbon particle. The oxygen carried with these ingredients burns the carbon to form carbon dioxide, which as a gas rises out of the glass. Sometimes sulfates are added, that they may rise to the surface and cut the scum which sometimes forms in melting, somewhat as a skim forms on milk when it is heated.

Sodium Nitrate

Sodium nitrate is added, not primarily for the sodium oxide content, but for the nitrate which helps to burn out impurities. Its use with arsenic, which acts as a carrier of the oxygen it gives off too easily, makes the glass look clear.

Sometimes salt cake, which is sodium sulfate, is used as a part of the source of alkalies. Salt cake used to be entirely a by-product in acid manufacture; now a great deal is natural salt cake, produced in western United States and Chile.

The soda which is used now is very pure, one of the tributes to the modern chemical industry. Formerly, soda and potash were both added in any form of salt that was obtainable. The problems involved in the use of large quantities of sodium sulfate were many, and when too much sodium sulfate was in the batch, carbon was added to help break down and remove the extra acid.

Cullet

In order to use up waste glass and to help in melting, "cullet" is used. This is the broken glass which you find around a glass house, and it is very readily crushed. It is mixed in with the batch to be charged into the furnace, or the pot, for melting again.

Geography of the Raw Materials

We begin to realize to what extent the glass industry calls on a great many mineral ingredients. These are brought to the furnace from all over the world. A typical fruit jar may be made from sand produced in New Jersey, West Virginia, Pennsylvania, Michigan, Illinois, Oklahoma, or California, according to nearness to the glass plant making the jar. Soda ash may come from New York, Ohio, or Michigan. The limestone may come from Pennsylvania, Ohio, Missouri, or California. Salt cake comes from Utah or South America. Boric oxide would come from California. Sodium nitrate all used to come from Chile, in South America, but it is now also made in the United States from soda ash and air. Feldspar is produced in Maine, Virginia, North Carolina, South Dakota, and Colorado; and other similar materials, such as nepheline syenite, come from Canada. Aplite is mined in Virginia, and lead oxide may come from Missouri. Sometimes a small amount of barium carbonate may be added from Tennessee or Georgia. A little arsenic, as a refining help, may be from Mexico or Montana. Then, because all the iron cannot be kept out and a slight green cast can be seen on the glass, a very, very small quantity of selenium is added. This may come from Montana or Mexico. Also, just as a little bluing is added in the laundry to whiten the clothes, one part in 400,000 of cobalt oxide is added to the glass to help whiten it. This may come from Africa. If the fruit jar is one with the zinc top and an opal liner, it would also have fluor-

spar from Illinois or Kentucky or New Mexico, which, when combined with the alumina in proper proportions, will produce the opal glass by making little crystals in the glass; it may have cryolite from Greenland for the same purpose. Manganese from the Caucasian Mountains is used in some glasses. Cadmium helps to make a ruby glass; it comes from China. Chromium, uranium, and copper are samples of other elements that come from all over the world.

Compositions

The following compositions are typical of how present-day glasses are made up. Notice that the sand and alkalies (soda and potash) and alkali earths (lime and magnesia) are the important ingredients, except in optical glass, which is made for very special purposes.

	Window Glass	*High Lead Optical Glass*	*Container Glass*	*A Pyrex Brand*
Silica	73–74	46.0	72–74	80.6
Iron oxide	0.1–0.2	0.02	0.04–0.07	0.1
Alumina	1–2	0.15	0.5–1.0	2.0
Lime	12.5–14.0	none	7–8.5	0.2
Magnesia	none	none	none	0.2
Soda	12.6–13.5	0.5	17–18	3.8
Potash	none	8.5	none	0.6
Lead oxide	none	44.5	none	none
Arsenious oxide	none	0.3	none	none
Boric oxide	none	none	none	11.9

2. MELTING

Pots

The old-fashioned way of making glass was in pots. The pots have grown from a capacity of only a few pounds until now they will hold a couple of tons of glass. They will stand five feet high, and for very fine tableware are covered on top, having a large mouth, facing the front, into which the batch is introduced. Also, into this mouth the workman reaches with a blowing iron, or an iron rod, used for gathering the glass, which is called a "punty." These pots are made out of a very special clay, able to stand extremely high temperatures, and to withstand the attack of hot glass, for the hot glass tends to dissolve some of the clay. It eventually does, after a number of melts, and a new pot must be used.

Optical glass is made in a smaller pot, open at the top. The workmen are very particular to keep all the dirt out of it. The reason the open pot is used is because, when the glass is filled and melted, it boils and bubbles, and finally settles down to a quiet melt. When all is ready, the pot is stirred and cooled just a little bit, though still hot, so as to let the bubbles redissolve. The whole pot is taken out of the furnace then and allowed to cool to break the glass, because optical glass is formed after picking out the perfect pieces of glass, by softening and pressing to whatever shape is desired for grinding.

Tanks

The bulk of glass, however, is made in tremendous furnaces, some of them holding several hundred tons. In the glass house, they are generally called "tanks," and truly they are tanks, sometimes 25 feet wide and up to 100 feet long, with glass from two to five feet deep. In the molten condition, this is called a "bath of glass." This tank is made of specially made blocks from specially chosen clay, fired to extremely high temperatures; some of them are electrically melted and cast. These blocks often weigh more than 600 pounds apiece.

These tanks are built in as part of the huge furnace, very much like an open hearth steel furnace. The fuel and air mixture goes in at one end, burns over the batch, goes out the other to warm up an open stack of bricks called "checkers" so that when the fire is reversed to go in the opposite direction, these bricks preheat the air to get ever and ever higher temperatures.

These tanks are large things, yet their temperature is controlled within a few degrees. The glass is kept at a uniform level so as not to develop irregularities called "cords," in which the glass forms streaks of a composition which is different from the main part of the glass.

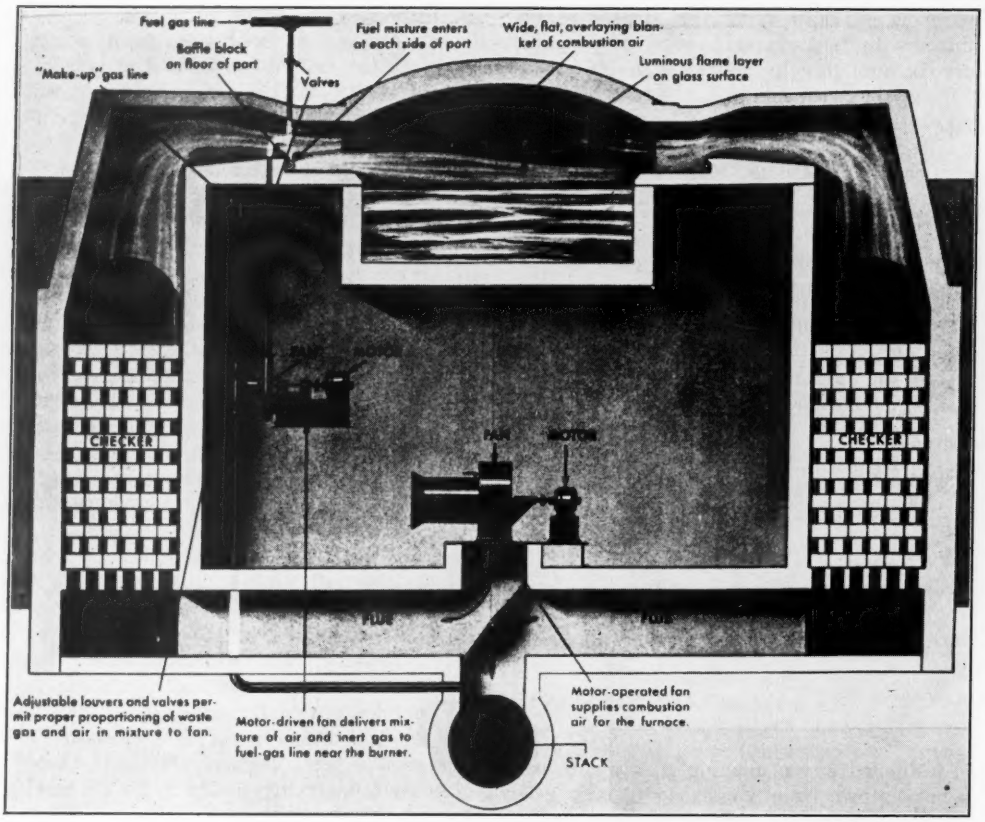
The tank is divided into two portions, the front third separated from the back two-thirds by what is called "the bridge wall" to keep impurities from moving forward. There used to be holes in the front end for men to gather the glass on the end of a pipe, or punty (French *pontil*); now most tanks let the glass flow out long snouts, like long, flat, tea kettle spouts. The glass does not flow in a continuous stream. As it slowly drops out, a pair of shears cuts it off. By control of time and temperature, very uniform weights of these "gobs" of glass are dropped into molds, where the machine makes the container. Of course, if this is a window glass furnace, the glass flows out in a long wide sheet, or comes through a continuous oven or lehr in which it is drawn up under an intricately controlled mechanism to give acres of window glass.

Fuel

One of the most important of the raw materials used in glass making is the fuel. For several thousand years, wood was the one fuel that was used. Then the English started using coal in the seventeenth century. In this country, the first glass furnaces used wood. The first furnace was built in Virginia, probably by the governor of Virginia. It was a very small one, and was made to manufacture beads used for trade with the Indians—our first money. In those small furnaces, wood was a logical fuel and an easy one, though it is hard to maintain a high temperature with wood. Furnaces were built in New England, New Jersey, and elsewhere so that they could be fed with the wood from nearby forests.

The first furnaces in the Pittsburgh district were built there because of the supply of coal, which was much better for higher temperature.

Coal continued to be the chief fuel in the United States until just the past generation, when we learned to use natural gas. Furnaces then moved to various parts of the country where natural gas was abundant. Coal is utilized better in what we call gas producers,


Fuel gas line
Baffle block on floor of port
"Make-up" gas line
Valves
Fuel mixture enters at each side of port
Wide, flat, overlaying blanket of combustion air
Luminous flame layer on glass surface
CHECKER
FAN
MOTOR
CHECKER
Adjustable louvers and valves permit proper proportioning of waste gas and air in mixture to fan.
Motor-driven fan delivers mixture of air and inert gas to fuel-gas line near the burner.
Motor-operated fan supplies combustion air for the furnace.
STACK

Courtesy of the Journal of the American Ceramic Society

VERTICAL SECTION OF GLASS TANK

which partly burn the coal, thus producing a combustible gas. Now oil is used as well as coal gas and natural gas.

The furnaces have stayed for the most part in the locations where they settled in the last fifty years. The seaboard furnaces, not having a local supply, are now able to get their fuel from farther away. Oil and gas are easily transported in normal times.

3. FORMING THE ARTICLE OF GLASS

Window Glass

Twenty-five years ago, most of the window glass in the United States was blown by mouth. Huge bottles were blown, the top and bottom of the bottle were cut off, and the sides were flattened in large furnaces. Now machines draw a five-foot-wide sheet of glass from the furnace, at any thickness desired, to produce even a better grade of glass than was ever blown by hand. The old cylinder process was an ancient one, and in turn it was an improvement on the older "crown" glass method. Crown glass was blown like a big ball, like a soap bubble, and the drop on the soap bubble is like the bull's eye which we see now in so-called antique glass windows. The continuous machine, making glass at one-fourth the price, makes possible the windows we have today.

Plate Glass

Plate glass is made like a pie crust; a big ladle, holding half a ton of glass, pours it while red hot on an iron table, where it is rolled out to one-half inch thickness. It is then slowly cooled and ground to about one-quarter inch thickness with sand and rouge until it shines with the polish we see in the plate glass windows of the stores. A continuous stream flows under a roller on a table and the hardened glass is continuously ground and polished for automobile wind shields, as well as store fronts.

Bottle Glass

The bottle machine is also very interesting. Where one man used to make a few hundred fruit jars a day, a machine turned by a motor will produce 20,000 fruit jars. These machine-made bottles are of a much better grade, that will last longer, and at a much lower price, so that fruit jars are a common article of commerce now. These machines go through all the effective motions that a man did, when he blew the bottle.

There are many different types of these machines, but in principle a "gob" of glass is placed in an iron mold. It is pressed into a shape, and a small hole is punched into it to start the bubble; compressed air is blown into the bubble, and the mold determines the

size and shape of the bottle. These machines are made to hold several molds, up to ten or twelve. They work continuously and smoothly, and deliver the glass to an annealing oven, where the bottle is very carefully heated to about 900°F. and cooled slowly so it will not break. This is a very important part of the process of making glass. This cooling, or annealing, is necessary in order not to leave any strain in the glass, which would ultimately crack it. Practically all glass is annealed by this method. It takes a very little while to anneal a thin electric light bulb—just a few minutes—because it is so thin. Large bottles take several hours. The furnace in which the annealing is done is called a "lehr." This is now run continuously, with the bottles on a chain belt, slowly going through the heat, and cooling off at a predetermined rate.

Glass Tubing

There is still a small amount of mouth-blown tumblers, beakers, etc. This is the equivalent of the handmade articles of other industries, because when a man reaches in with a hollow pipe and gets a gather of glass on the end of it, he blows it into a mold which controls the size and shape of the bubble which he makes. When this bubble freezes, the tube is cut off and "fire polished" so the glass will not cut. Laboratory ware, being made of especially hard glass, is more difficult, because the temperature has to be higher before the glass can be blown by mouth. Tubing is quite interesting because by dropping a continuous flow of glass over a rotating hollow clay cylinder, with a little air blowing in at one end, the glass can be drawn off quite rapidly at the other end and have a hole in it, annealing as it goes along. All that is necessary then is to cut it into lengths.

4. ANNEALING

Originally, all glass was put into a beehive oven, heated, then sealed up and allowed to cool by letting the whole oven come down to room temperature, which often took two weeks.

On items as large as the 200-inch disc for the Mt. Palomar telescope (17 feet wide and several feet thick), it took the better part of a year to anneal, because the heat had to be taken out of the interior of that large mass so very slowly.

Sometimes, instead of the glass being slowly cooled, it is purposely strained by blowing air on it. This is done for rear-vision lights in automobiles, because it toughens the glass against fracture. However, when it does break, it breaks into "a thousand pieces."

5. CHEMICAL AND PHYSICAL PROPERTIES AND METHOD OF TEST

We have talked about the materials that are used in glass and their chemistry as they are combined with fire. We must also talk about some of the physical properties that are given to glass by the use of these materials.

Chemical Durability

The properties which make glass a desirable material for our use are numerous. Outstanding is the chemical durability. This is the resistance which glass offers to the chemical attack of foods, water, drugs, and anything in contact with it, and is a very important property of glass.

There is no such thing as a perfectly resistant glass. Even silica itself can be attacked sometimes. Hydrofluoric acid, as an outstanding example, will dissolve silica bottles. There has been a good deal of work done, however, to produce the most durable glass possible, and great progress has been made. The ancient glasses were what a glass man would call "soft." They were made for low temperature melting, with wood, and contained considerably more alkali which was easily leached out by the water. The patina on the ancient glasses was just produced by carbon dioxide and other chemicals in the atmosphere over a long time. Nowadays, by using a higher temperature, less alkali, and with other auxiliary ingredients as alumina, glass is made quite resistant. Occasionally, special products have to be put into glasses made particularly to resist those products, but the modern glass has gone a long way toward developing the perfect container. Windows do not "fade," or get a permanent scum on them, as they used to.

Viscosity

Viscosity, or the resistance to flow, is a very important property to the maker of the glass. It is this ability to stiffen slowly on cooling that gives time for the many operations of pressing, blowing, and reworking.

Its measurement, determined in poises (C. G. S. Unit used in the measure of viscosity) is about as follows:

	$\text{Log}_{10}\ \eta$	η
Softening temperature	7.65	4.5×10^{7} poises
Annealing temperature	13.40	2.5×10^{13}
Strain temperature	14.60	4.0×10^{14}

The experience and knowledge of the science and engineering of glass manufacture make it necessary to develop and use tests which will give the needed information. These are not used on all glasses, or on any of them all the time. For instance, the coefficient of expansion is only occasionally measured on a bottle or window glass. Uniform chemical analysis of the "batch" ingredients and of the glass will keep this physical property within reasonable control all the time, but for glasses made to withstand an unusual thermal shock or to join with other materials, a standard form of expansion test is more frequently made.

Coefficient of Expansion

When glass is desired for a purpose that demands great resistance to changes in temperature, it may also be desired for other properties. It may be used as a container, when chemical durability is also demanded, or it may be desired to use the glass for its effect on

light rays passing through it. In other words, it may be desired for optical glass, when light is refracted or bent, or for color effects as in cathedral windows or tableware or for colored designs on bottles.

The expansion of glass would be of interest only when it is to be joined to another glass or metal, except that it is a very important part of the cause of glass breakage. Iron expands more than glass, but it will give when it is under strain. Glass is more rigid—more stubborn—so when a part of a piece of glass expands with heat and another part does not, a tension is set up which may exceed the ultimate tensile strength of the glass, and it will break. The engineering formula for the thermal endurance of glass has in it, as its most important factor, the coefficient of expansion.

In a bottle factory, a short cut called a thermal-shock test may be used as a control test in which the article may be alternately heated and cooled to check its durability. The change generally is from hot to cold, and the test is based on the fact that glass breaks practically always from a tension strain, not from compression.

Composition Checks

As mentioned before, the chemical composition and method of making the glass determine its physical, as well as chemical, properties. These include the specific gravity which is used to check composition, when the annealing is known, or to check the annealing, when the composition is known. All this sounds very complicated, but it is not. If the glass has been made with a heavier material, such as lead oxide, it will be heavier.

Courtesy of the Bulletin of the American Ceramic Society
POLAROID POLARISCOPE

Accurate measures have been made of the effect of each of the ingredients used. Specific gravity tests are simply made in the standard manner, but always the annealing must be constant, or in other words, the thermal history must be checked. This is because glass, by its very habit of slowly hardening on cooling, may "set" so that the glass is still expanded as it was at an elevated temperature. That this is related to the molecular arrangement of the silica need not be discussed here.

Strain

For regular production tests on glass, one of the most valuable is the use of the polariscope or the polarizing microscope. The effect of elliptically polarized light on passing through crystals is an interesting phenomenon. Glass, by its very nature, is not crystallized, and, when under no strain, it shows no effect on the polarized light. If it is under a strain for any reason, interference bands measure the amount and direction of this strain. By the use of a quarter-wave-length retardation plate, colors aid in the indication, and with the Babbinet compensator, measures can be made of the amount of strain. All this is vitally necessary for the testing of glass, because, like all articles of manufacture, it has its weakness.

Cords

The problem of making good glass in large or small amounts is the production of a uniform composition, uniformly cooled to relieve all strain. Lack of uniform composition is evidenced by "cords," or streaks of glass of slightly different composition. These are hard to get rid of because glass cannot easily or effectively be stirred, and it has a strong tendency to dissolve the inner surface of the container in which it is made, or to volatilize some of its constituents on long heating. Methods of attaining the proper degree of perfection depend on the ability to measure the cords, as different compositions cause different rates of expansion, which cause strain; the polariscope makes this visible. So, too, when the glass piece is formed at a high temperature, it may be at equilibrium with all its parts, but it must be cooled slowly enough that it will not "set," or become rigid, in one part while another is still soft. If it does, a strain will result which is located by a polariscope. The most difficult part of correcting a trouble is in locating the cause; the cure follows easily.

There are many other tests based on physical or chemical properties of the glass and their variation with composition or treatment just as there are with the metals. These tests have grown up with time and research. It is a long way from the efforts of the early glass maker with no technical skill and little experience to draw on. But slowly, at first by observation, then by borrowing knowledge from other fields, glass has finally developed the possession of a full-fledged science of its own.

HISTORY

We do not know the beginnings of glass. Our picture of the earliest civilization is based on material dug up

from graves and buried treasures. Intermingled with the stone articles found in the earliest graves were bits of pottery, a logical next step from the use of natural stones, which were just shaped by chipping, to the making of an artificial stone by burning clay.

The next step seems to have been the melting of glass, which is an artificial rock anyway. The oldest piece of glass ever discovered was found at Tel Asram, near Bagdad. It is dated about 2900 B.C., or roughly, nearly 5000 years ago.

We know that the Syrians made glass and sold it to the Egyptians, and later the Egyptians made their own, and sold some of it to the Syrians.

This brings us, with one jump, up to about 1400 B.C., a mere matter of 1500 years. The glass then was not what we are used to thinking of as glass. It was mostly jewelry, such as beads and small hollow vessels made for perfumes. The method of making a jar or small phial was to form a small clay mold of the interior of the bottle. The glass was gathered on the outside of this mold and then pinched and somewhat shaped, with a few decorations put on it by dropping other glass on top of it while it was still hot. After the glass had cooled, the clay was dug out of the inside of the so-called bottle. This left a rough interior, and made it rather difficult to produce very elaborate shapes. The glass in those days was only for the few who could afford it.

The ancient glasses obtained their decoration by the application of threads or pieces of other colored glass to the surface of the article while still hot. The next natural step was the gathering of several layers of glass of different colors and then cutting through the top layers. This was a logical progression from the cutting of gem stones, some of which had natural layers of different colors. It must be recalled that gem stones and decorative artists' work are very old possessions of humankind.

At this early time, glass was not decolorized, the natural colors of the minerals being the only way of producing variation. Shapes were limited. There are many examples of these glasses in various museums, notably in the Metropolitan Museum in New York and the Libbey Museum in Toledo.

The glass was then melted in small pots, not much bigger than a large flower pot. It melted at a low temperature, and was full of blisters and irregularities, but it sufficed for the purpose at the time, for accuracy of dimensions and perfection of design were not yet developed.

About the beginning of the Christian era, men learned to blow glass, using a hollow pipe. This meant the production of bottles of much larger size, of thinner walls, and more intricate design. As a result, the glass began to get better. They had to have more perfect glass melted in order to blow it, though all of this old glass was still very crude. At about this time, glass-making of a kind spread into various portions of Europe, where it existed for a while and slowly died out, to be revived again later on. The real center of glass work was in the Byzantine Empire. It is interesting to see that the decorations they used followed the same general trends that were used in decorating ceramic ware and buildings.

The only thread of continuity that amounted to anything was Venetian glass. They developed larger pots, and, with the help of purer materials, made more transparent glass. Living on islands, they were able to keep a good many of their developments a secret. They formed guilds, and threatened with death anyone who gave away their methods.

As always, in those ancient times, superstitions formed a large part of the craft. There is still an old saying that "a salamander can live in fire." This is a little, red-brown-colored water dog we see in streams. All Venetian glass blowers thought that there was a salamander living in every furnace, and when a man was not true to his guild and mysteriously disappeared, they said the salamanders came out of the furnace and ate the informer. To this day, that part of the glass furnace into which the glass is fed is still called the "dog house."

This monopoly lasted in Venice for about 400 years. By keeping the secret as they did, the Venetians only made people all the more anxious to find out what it was. Then the Crusades made the people of Europe more interested in glass, along with the other cultural acquisitions from the East. After a while, the other countries, Germany, England, and France, wanted to develop glass making, which to this day is centered in the parts of these countries where it originally started. All this took centuries to accomplish, for it went along with the slow stabilization of Europe and the development of Gothic art. Commerce thrived, and, with more money and leisure, came culture and the desire for better things, like stained glass windows and glass wine cups.

From the very old method of gathering glass on a clay mold, it was thousands of years before the ancients learned that they could press the glass into shallow shapes by the use of metal molds, still called pressed ware. This, of course, gave different effects, different decorations, and the possibility of surface design, but was limited to articles that were wider at the top than at the bottom, so that the plunger or metal pressing iron could be easily removed. It was again hundreds of years before the art of blowing glass was developed. It should be recalled that the ancient glasses were really melted only to paste form, and it was not until experience and chance pointed the way that the ability to blow a bubble of glass appeared, which produced blown ware and allowed for the thinner and more artistic shapes which followed. Venice developed this, and, along with her citizens' love of color, made a glass which is still typical of what is produced in northern Italy today.

The ancients had developed the use of cutting opaque glasses as they made them, but at that time they did not know how to decolorize the glass so as to make it colorless, and it was not until comparatively recent

times, probably in the sixteenth century, that real cut glass was developed. It was in England, where better fuel and purer materials were used, that cutting really became popular. There began the use of lead oxide in glass instead of the old sand, soda or potash, and lime. This made a glass that showed the sparkle of the cuttings. The English also found that by using pure flint pebbles, instead of sand, they could get a more colorless glass; thus, the origin of the name "flint glass," which still, in optical glass, means a lead glass, though in general it may mean any clear, transparent glass.

This last 100 years has seen more progress in the manufacture of glass than all the previous 5000 years. Scientific workers, machinists, and engineers have taken the former crude efforts and developed large furnaces, large machines, and low costs, so that glass is no longer a luxury commodity, but a common article of commerce, considered necessary to our daily lives. They have extended the types of glass so that optical glass has gone farther than Schott of Jena ever dreamed. Also, heat-resistant glasses, which were formerly a laboratory rarity, are now common household articles. Window glass has made light the houses in which we live—two hundred years ago it was an expensive luxury.

Preserving foods was first developed in glass jars, still used as the "fruit" jar today. It is the parent of the tin can, which makes possible more varied and palatable foods the year round. Drinking glasses have completely displaced the pewter mug. Mirrors, once made of polished metal and of very restricted use, are now found in every purse, on every automobile, and in every washroom. Thermometers, watch faces, drug containers, and electric insulators are not rarities or luxuries; they are everyday necessities of better living.

In short, whether we use it for objects of beauty or of humble utility, for everyday windows, or for the tools of the scientist, glass is one of the most vitally important materials of our civilization, and we are only at the beginning of its possibilities.

LETTERS

Buffer Capacity

To the Editor:

A recent article[1] discusses the buffer capacity of a weak monobasic acid being titrated with a strong base. Though the conclusion reached as to the region of greatest buffer effect is correct, several of the intermediate steps are apt to confuse the student.

In the first place, it should be pointed out that the letter C as used in the article mentioned does not denote the *concentration* of acid at any time but, rather, "milliequivalents of acid originally present," and, similarly, (A^-) denotes "milliequivalents of base added."

The equation,

$$\text{pH} = \log \frac{1}{Ka} + \log (A^-) - \log [C - (A^-)]$$

which is derived from the law of mass action, depends upon concentrations, but it holds also when the terms are defined as above, since the varying amount of water present dilutes (A^-) and C alike. On differentiating we find

$$\frac{d\text{pH}}{d(A^-)} = \left[\frac{1}{(A^-)} + \frac{1}{C - (A^-)}\right] \log_{10} e$$

Inclusion of the factor $(\log_{10} e)$ does not change the minimum as found in the cited article, but it should be taken into account in computing the slope of the function.

Finally, it will be instructive to obtain $d\text{pH}/dV$ where V is the volume of base added, so as to have the slope of the titration curve at any point. We can do this by the relation:

$$\frac{d\text{pH}}{dV} = \frac{d\text{pH}}{d(A^-)} \times \frac{d(A^-)}{dV}$$

Since (A^-) in the example given $= V/5$,

$$\frac{d\text{pH}}{dV} = \frac{1}{5} \frac{d\text{pH}}{d(A^-)}$$

At the point of maximum buffer capacity, when half the acid has been titrated, the slope of $d\text{pH}/d(A^-) = 0.868$ and the slope of the titration curve $d\text{pH}/dV = 0.174$.

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[1] PARK, "The region of maximum buffer capacity," J. CHEM. EDUC., 19, 171 (1942).

There's Money in It

To the Editor:

There is one branch of metallurgy which has not yet received adequate attention, at least as far as my reading extends—namely, alloys for coins.

Today, as since the beginning of history, gold and silver are alloyed with copper. Bronze coins also come from antiquity and nickel is the only modern addition except that for a short time platinum coins were in circulation in Russia.

With the great recent increase both in the knowledge of alloys and their properties and fabrication, there should be new alloys for coins and I suggest the following specifications:

Coins should be of distinctive colors as at present, yellow for gold, white for silver, brown for bronze, and

possibly some shade of blue or green for token coins. They should be hard enough to stand hand-to-hand wear for thirty years and should not be attacked by perspiration or H_2S or H_2CO_3.

Available for alloys are V, W, Mg, Be, Zn, Cd, Ce, Cr, Mo, Mn.

Perhaps some coins could be made to glow in ultraviolet light.

F. W. SMITH

VIA NOGALES ARIZONA
GUASAVE SINALOA, MEXICO

English versus Metric System

To the Editor:

An inexplicable puritanism seems to characterize most writers of textbooks in general chemistry when a question is raised concerning the use of the English system of weights and measures. "The metric system," they say, "must be emphasized to the exclusion of any system which was based originally upon the size of someone's foot, or the length of his arm, or the height of his horse." "Scientific measurements must be kept undefiled by using only a scientific system"—even if it results in such curiously logical figures as 273 and 22.4. Believing possibly that the metric system is the only "scientific system," the academician exhibits a certain missionary zeal in spreading this gospel to the innocent undergraduates in the hope that his students will never know anything else or be required to use any other units of weight, length, and volume.

Our colleges are supposed to train students in the fundamentals of chemistry, so that they may eventually take their places in the industry. What a shock it is to many of them to learn that liters and kilograms give way to gallons, cubic feet, and pounds. Especially is this true in the plant; less obvious in the research laboratory. Many new graduates are still more amazed to learn that simple calculations of volumes and weights do not require the use of conversion tables from the metric to the English system. The figure 22.4 is no more mysterious than is the number 359. The same concepts which govern the fundamental volume and weight relationships, as expressed in liters and grams, can be worked out for cubic feet and pounds.

Why then do we not teach in our courses in general chemistry the relationship between the pound mol and the pound molecular volume (in cubic feet)? Why not have students work out the absolute zero on the Fahrenheit scale and calculate volume changes of gases with variations in degrees Fahrenheit? Possibly we are wrong in accusing our teachers of general chemistry of trying to jam the metric system down the throats of their students because they feel that it is the only system which should be used. We suspect instead that the average chemistry teacher is entirely unaware that such simple relationships exist within the English system.

Price lists of chemicals as quoted in trade and professional journals are practically always specified in so much per pound or gallon. Capacities of industrial equipment, of reactors, of autoclaves, and of most large scale chemical apparatus are given in cubic feet or gallons. Steam pressure tables give pressures in pounds per square inch or inches of mercury. Why, in the face of this overwhelming use of the English system, do we disregard and neglect it so utterly in our general courses in chemistry?

It would, of course, be most desirable if a uniform system were adopted and maintained. There is little question as to the superiority of the metric system over the English system. But as long as the research worker and the academician use the metric system while the chemical engineer, the plant chemist, the chemical salesman, and many engineering specialists use the English system, it would seem desirable to give all chemists training in both.

There are a few very simple instances where the English system may properly be introduced in a course in general chemistry to supplement the metric system. Students become quite familiar with the fact that one gram mol of a gas at standard temperature and pressure occupies a volume of approximately 22.4 liters. They should also know that one pound mol (the molecular weight in pounds) of a gas occupies a volume of 359 cubic feet at 32°F. and a pressure of one atmosphere. There is nothing difficult or unusual about this statement. In teaching students that a balanced chemical equation represents actual as well as relative weights why not make use of the pound mol and the pound molecular volume? This relationship involving units of the English system makes it possible to calculate the weight in pounds of a given volume of a gas expressed in cubic feet, the volume in cubic feet of a given number of pounds of a gas, and the volumes in cubic feet of gases, either as reactants or products, involved in any chemical reaction which can be expressed by a chemical equation and in which weights are given in pounds. It should be clearly pointed out that 359 cubic feet is not identical with 22.4 liters.

If the volume of a gas increases $^1/_{273}$ for a rise in temperature of one degree Centigrade, it is perfectly obvious that the volume should change regularly with variations in degrees Fahrenheit. Since one degree Fahrenheit is a unit equal to $^5/_9$ of a degree Centigrade, one would expect the volume change to be only $^5/_9$ as great for a rise in temperature of one degree Fahrenheit (that is, a change of $^1/_{492}$ of the original volume per degree Fahrenheit). In effect the absolute zero (−273°C. or 0°K.) is 492° Fahrenheit below 32°F., or approximately −460°F. This relationship is expressed by the absolute Fahrenheit scale or the Rankine scale. °R. = °F. + 460 (approximately). Volumes of gases can therefore be calculated just as easily whether temperatures are expressed in degrees Centigrade or degrees Fahrenheit. In the latter case conversion into degrees Rankine is all that is necessary.

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Out of the Editor's Basket

THE American Cyanamid Company (30 Rockefeller Plaza, New York City) recently distributed a hundred exhibit cases displaying some of the chemical products of the Company. These went to a number of the leading universities and technical schools and the supply is now entirely exhausted. Nevertheless, the Company has a supply of wall charts, replicas of the panels in the exhibit cases, which they will be glad to send to any college which applies. Beyond this, they will be made available to high schools, as long as they last.

● We recently received from the W. M. Welch Scientific Company (1515 Sedgwick Street, Chicago, Illinois) a publication entitled: "Duo-Seal Pumps and Vacuum Technique." This not only describes available equipment but also contains some excellent theoretical and practical matter on the construction and operation of vacuum systems.

● The medal of The American Institute of Chemists, presented annually for outstanding service to the science of chemistry and the profession of chemist in America, was awarded this year to Dr. William Lloyd Evans, chairman of the Department of Chemistry, and professor emeritus, of Ohio State University, Columbus, Ohio.

The award was made in recognition of Dr. Evans' outstanding accomplishments in the field of oxidation of organic compounds, particularly in the oxidation of carbohydrates; and for his contributions to the profession as an educator.

● War demands have created unusual opportunities for technically trained persons in federal employment. The United States Civil Service Commission is now seeking Junior Chemists to perform research, investigative, or other work in some branch of chemistry. The positions pay $2000 a year. No written test is required. Applicants' qualifications will be judged from their experience, education, and training.

Women especially are urged to apply. The Navy yards, arsenals, and other government laboratories, it is reported, are now employing women in chemical work. Completion of a four-year course in a recognized college with 30 semester hours in chemistry is required, although senior students who will complete the required course within four months of the date of filing application may apply. No experience is required, although preference in appointment may be given to applicants showing experience in chemical or related work.

There are no age limits for this examination. Applications must be filed with the Civil Service Commission, Washington, D. C., and will be accepted until the needs of the service have been met.

● It is reported that the Civil Service Commission is especially anxious to get chemical engineers, particularly in the Explosives option, in the grades from $2600 to $3800. The demand is great at this time in grades from $2600 to $4600 in nearly all fields of chemical engineering.

● It is well known that airplane factories have been employing women mechanics for months, replacing men who have been called into the service. It is not so well known that the present emergency has also created a demand for women in the professional field. As the last war gave women an entree into positions which had previously been men's prerogatives, the present war is opening a new field for women—that of chemists in research laboratories.

While the prejudice against women's invading what was formerly man's domain has not been entirely overcome, at least it has been modified by the emergency. With the Army and Navy taking research chemists from their jobs, and even undergraduate chemists, this profession, like so many of the industries during war times, is turning to women to fill vacant positions.

● A recent report from the Wartime Commission of the U. S. Office of Education discussed the question of teacher-shortage. It pointed out that there is either an appreciable shortage, or a shortage that is developing, in many parts of the country in rural schools, elementary schools in rural or small town areas, vocational agriculture, home economics, trade and industrial education, business subjects, physical education, nursing education, music, physics, chemistry, mathematics, and a few other subjects. There has been a surplus, in some places, of teachers of English, social studies including history, and foreign languages, and possibly a few other subjects. These surpluses are steadily decreasing.

● Among many interesting features of the centralized sterilization room of the Jefferson Hospital in Philadelphia is an automatic device for checking and recording the purity of distilled water.

Water is provided by a ten-gallon-per-hour automatic still. The effluent flows through a conductivity cell which is connected to a recorder. This combination measures and records the electrical resistance of the distillate. A continuous record is made, and if the resistance falls below a certain value, showing that the water is not pure enough, a red light flashes.

Principal advantages of this method of analysis are that it largely eliminates the human equation, and that it provides a graphic record, always available for consultation. It checks every drop of water instead of occasional grab samples. It wastes no water. Since the purity is recorded, the station supervisor can watch not only for sudden or temporary changes but for gradual

ones due to aging of equipment, seasonal differences in raw water, etc.

● Explaining that molecules associated with the production of fluorescent light tire as easily as humans, Dr. N. C. Beese, research engineer of the Westinghouse Lamp Division, recently released results of exhaustive tests he conducted in order to determine the fatigue effect upon molecules when exposed to ultra-violet light.

When molecules of fluorescent materials start to work, they are efficient and highly productive, but over a period of time, under continued exposure, they lose much of that efficiency and tend to slow down. If the molecules are given rest periods in the dark, they regain their original strength, much the same as human beings.

● The First Annual Science Talent Search, made possible by the Westinghouse Electric and Manufacturing Company as a contribution to the advancement of science in America, provides forty all-expense trips to Washington for a final examination with awards of eighteen Westinghouse Science Scholarships of $200 each and two Westinghouse Science Grand Scholarships of $2400 each. One boy and one girl will be selected as winners of the Grand Scholarships.

The Science Talent Search is designed as a major step toward making available potential scientific talent to important tasks in war and peace. Within the next five years, either in war or peace, boys and girls now in high school must begin to take leadership in scientific research and engineering.

RECENT BOOKS

INORGANIC CHEMICAL TECHNOLOGY. *W. L. Badger*, Manager, Consulting Engineering Division, The Dow Chemical Company, and *E. M. Baker*, Professor of Chemical Engineering, University of Michigan. Second Edition. McGraw-Hill Book Company, Inc., New York City, 1941. xi + 237 pp. 58 figs. 15 × 23 cm. $2.50.

The first edition of this book appeared in 1928, with 228 pages of text and 54 figures. The authors state that about a third of the illustrations in the present edition are new and that much of the text has been rewritten.

It is strongly emphasized in the preface that the book is a textbook, not a handbook. This emphasis is scarcely needed, for the new edition, following the plan of the first edition, covers only a very small part of the broad field of inorganic chemical technology. It appears to the present reviewer that the book might well be twice its present size without danger of being considered a handbook, and with a considerable increase in its usefulness as a textbook.

The authors state that the reason for the new edition is that much of the practice described in the first edition is obsolete. The present reviewer would add that some parts of the new edition describe practices which are as obsolete as a dodo's egg. Figure 27 and Figure 28 and the accompanying text are examples of this, and many others might be cited.

The authors modestly confess that they are not able to speak *ex cathedra* on current practices in all fields but have had to depend on the literature. It is not evident to the present reviewer, however, why the authors have chosen in so many instances to *disregard* the literature of the past ten years. As an example of this, the electric furnace process of smelting rock phosphate, described on page 131, is based on articles which appeared in 1929 and 1932, when the art in this field was in its infancy.

The book contains many erroneous statements, too many to be pointed out within the limits of a book review. As a sample, consider page 201, on which may be found nine errors of fact—a high score, even for authors who do not claim to speak *ex cathedra*.

Some parts of this book are excellent, particularly those parts in which the authors are able to speak *ex cathedra*. It is to be regretted that chemical engineers as able as the authors of this book should be so careless in bringing forth a new edition of their textbook. Even the McGraw-Hill Book Company has caught the spirit of the occasion, as the title to Chapter IV on page IX bears witness.

HARRY A. CURTIS

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OPTICS AND SERVICE INSTRUMENTS. Reprinted by Permission of the Controller of His Britannic Majesty's Stationery Office. First American Edition. Chemical Publishing Company, Inc., Brooklyn, New York, 1941. 128 pp. 112 figs. 13.5 × 21.5 cm. $1.75.

In a very concise manner, this book explains the elementary principles of the science of optics. The topics included are: nature of light, rectilinear propagation of light, reflection at plane and at curved surfaces, refraction, total internal reflection, prisms, lenses, optical instruments, telescopes, binoculars, etc., testing and adjustment of optical instruments, the eye, and dispersion and color. The book has explanatory and illustrative diagrams throughout.

HOW TO SOLVE PROBLEMS IN GENERAL CHEMISTRY. *Joseph A. Babor*, Associate Professor of Chemistry, and *Chester B. Kremer*, Instructor in Chemistry, College of the City of New York. Thomas Y. Crowell Company, New York City, 1941. viii + 88 pp. 14.3 × 21.7 cm. $0.75.

A handbook on solving fundamental chemical arithmetic problems.

UNIVERSITY PHYSICS. *F. C. Champion*, M.A., Ph.D. (Cantab.), Lecturer in Physics, University of London. Blackie and Son, Ltd., London and Glasgow, 1941. (Interscience Publishers, Inc., New York City.) Part III. Light—172 pp. 145 figs. 14.5 × 21.8 cm. $1.50. Part IV. Wave-Motion and Sound—67 pp. 42 figs. 14.5 × 21.8 cm. $1.65.

Intended for a first- and second-year course in college physics, this book deals in the third volume with the fundamental properties of light, reflection, refraction, coaxial optical systems and thick lenses, defects of the image in optical systems, dispersion, optical interference and diffraction, double refraction and polarization, the emission and wave theories of light, spectra and color, optical instruments, velocity of light, and photometry. There are 75 examples, with answers and hints for solution, at the end of the volume. The text is well illustrated, with the treatment mathematical in general.

The fourth volume in the series, on wave motion and sound, deals with the fundamental properties of wave motion, velocity of sound, propagation of sound through gases, vibration of solid bodies, the production and detection of sound waves, measurement of frequency, intensity of sound, and acoustics. Twenty-five examples, with answers and hints for solution, appear at the end of the book.

CHROMATOGRAPHIC ADSORPTION ANALYSIS. *Harold H. Strain*, Ph.D., Carnegie Institution of Washington, Stanford University, California. First Edition. Interscience Publishers, Inc., New York City, 1941. x + 222 pp. 1 color plate and 37 figs. 15 × 23 cm. $3.75.

This is the most up-to-date book on a very important analytical technic which was first discovered by Tswett in 1906 but remained practically unknown for many years. Essentially, chromatographic adsorption analysis consists of three steps: (*a*) passage of the unknown mixture, dissolved in a suitable solvent, through a column of the proper adsorptive material, (*b*) development of the chromatogram, *i. e.*, fractionation of the mixture, by washing the column with more (usually modified) solvent, and (*c*) mechanical separation of the obtained "bands" and subsequent elution of the adsorbed material.

Since 1931, when crystalline carotene was first separated into two fractions by adsorption upon columns of fibrous alumina, interest in this method has grown steadily, with the result that a great variety of applications has been demonstrated. Among these one finds not only studies of nearly all classes of organic compounds and isolation of many naturally occurring products, but also resolution of mixtures of inorganic ions and even separation of isotopes. Although originally designed only for colored substances, the method has been extended to colorless materials, with the aid of ultra-violet light, or by means of chemical reactions which produce colored compounds either before or after the adsorption.

All these analyses have so far been empirical and a general underlying theory has not yet been developed. Nevertheless, it has been possible to make some predictions and to give certain directions of procedure, due to many existing regularities between the adsorbability and the chemical structure of similar molecules. This is pointed out by the author who has presented lucidly and with excellent organization material contained in over 800 published articles. With emphasis on the experimental procedure, he has clearly shown the essentials so that even the novice should be able to apply this relatively simple and inexpensive method.

The first chapter, a brief Historical Introduction, is followed by a general discussion of Applications of Chromatographic Adsorption Methods. The next four chapters, Apparatus and Procedure, Adsorbents, Solvents and Eluants, and Location of Colorless Adsorbed Substances, contain the necessary general information. Tabular presentation of some of the material makes the use of this section especially simple. Chromatography of Inorganic Compounds, the next chapter, is brief, being one of the most recent developments. This is followed by the largest chapter, Chromatography of Organic Compounds. This topic includes aliphatic and aromatic substances, cyclic compounds, sterols and related compounds, vitamins, hormones, enzymes, co-enzymes and proteins, anthocyanins, pterins, chlorophylls, derivatives of hemoglobin, bile pigments, carotenoids, coal tar dyes, and various natural substances. The final chapter summarizes the Industrial Uses of this method. An extensive bibliography with subject titles and Author and Subject Indexes complete the volume and make it extremely useful for reference purposes. It is neatly bound, clearly printed, and well illustrated. Only few errors were noted, the most obvious of which are in the structural formulas of the sterols.

The book is highly recommended to student and teacher alike.

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SEMIMICRO EXPERIMENTS IN GENERAL CHEMISTRY. *W. Bernard King*, Assistant Professor of Chemistry, Iowa State College. Prentice-Hall, Inc., New York City, 1941. xvii + 137 pp. 18 figs. 15 × 23.5 cm. $2.50.

In adapting semimicro procedures to the needs of beginning students, the author has made a signal success of a task that frequently has been declared impossible. The experienced teacher of general chemistry will find that the manual contains most of the experiments that he has come to regard as classical, although he may find some novelty in a few of the materials used It is evident, however, that this manual was not produced by a mere scaling down of quantities used in macro experiments. There is ample evidence of careful laboratory checking of the directions.

Quantitative relationships are adequately stressed, but not overemphasized. Four of the forty-three experiments require determination of weight with a precision of one milligram. Introduction of the modern acid-base concept, a simple determination of pH, and an experiment on buffer action can be cited as valuable innovations. Experiments on eight simple organic compounds and suggestions for eleven inorganic preparations are included.

Directions are concise and clearly written and are reasonably free from "cookbook style." A few well-chosen questions are given with each experiment. Perforated pages are provided for the student's record of observations and results. Simple procedures are given for the identification of both metallic and acid ions, but these cannot be called a course in qualitative analysis. Rather, as the author indicates in his preface, the entire manual has been designed with the idea of giving students adequate preparation for semimicro qualitative analysis.

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OUT OF THE TEST TUBE. *Harry N. Holmes*, Ph.D., Oberlin College. Third Edition, Revised and Expanded. Emerson Books, Inc., New York City, 1941. x + 305 pp. 102 figs. 15 × 23 cm. $3.00.

With the present popular interest in the work of science, this book should help to make the subject of chemistry more understandable and vivid to the layman. Told in simple, human, interesting, and often humorous language, it traces the development of man's chemical knowledge from earliest days to the present, wherein chemistry has such a far-reaching influence on modern life. The heterogeneous collection of facts about the effects of chemistry has been organized into a swiftly moving, logically developed story, illustrated with numerous pen and ink sketches and diagrams. This is a book for all who know very little about chemistry and would like to know a great deal more without going into the technicalities which would be of interest only to the specialist.

TYPICAL QUESTIONS AND PROBLEMS IN GENERAL CHEMISTRY. *G. N. Quam*, Associate Professor of Chemistry, Long Island University. Sixth Edition. Edwards Brothers, Inc., Ann Arbor, Michigan, 1941. vi + 11 + 102 pp. 21 × 27.5 cm.

This sixth edition of the work has had the chapter on "Review of Some Arithmetical Operations" of the previous edition replaced by the more elaborate treatment, "Part I—Review of the Mathematics for General Chemistry." "Part II—Typical Questions and Problems in General Chemistry" follows the general plan of the fifth edition. New problems, sample problems, and questions have been added. In line with the designation of volume on glassware and in the literature, volumes are stated as liters and milliliters, in place of liters and cubic centimeters. Many references to recent articles in chemical periodicals have been added or substituted.

SOLUBILITIES OF ORGANIC COMPOUNDS. A COMPILATION OF QUANTITATIVE SOLUBILITY DATA FROM THE PERIODICAL LITERATURE. *Atherton Seidell*, Ph.D., National Institute of Health, Washington, D. C. Third Edition, Volume II. D. Van Nostrand Company, Inc., New York City, 1941. 926 pp. 14.8 × 23.4 cm. $10.00.

Quantitative solubility data concerning organic compounds, arranged in order of their increasing content of carbon, hydrogen, and oxygen, with a cross-reference name index at the end of the volume. An author index gives references to original sources of data. An invaluable reference book.